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ECONOMIC GEOGRAPHY

OCTOBER

THE ALUMINUM INDUSTRY OF THE WESTERN HEMISPHERE

James E. Collier

WATER SUPPLY GEOGRAPHY OF THE BASIN OF THE RED RIVER OF THE NORTH IN THE UNITED STATES

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AGRICULTURAL ECONOMY OF THE LAGUNA REGION

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Miss Garloch, Chief of the Reference and Circulation Department at the Library of the University of Pittsburgh, concludes in this issue a series of articles on the role of Cotton in Mexico's economy. The present article is the third in the series.

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ALUMINUM

IN all the long and fascinating history of man's use of metals, the development of the aluminum industry forms one of the most thrilling chapters. It is distinctly a modern industry, a product of a civilization far advanced in technology and science, and consciously seeking new activities, new methods of expansion, new products for use and enrichment of life. It has not passed through the long centuries of primitive and fortuitous experimentation and evolution of technique that bronze and iron and copper and pewter and so many other metals and alloys have required. Little more than a quarter century spans the period from its first commercial production to its present varied and widespread use.

The winning and working of metals and metal derivatives constitutes one of man's most spectacular technical achievements. The whole relatively brief period of man's cultural evolution since the stone age, very brief in time by comparison with duration of the stone age, has been marked principally by his rapid progress in the skilled technique of smelting and refining the ores and molding, tempering, alloying, plating, and otherwise processing the metals, alloys, and eutectics derived from them. Remarkable as have been the techniques of spinning and weaving, of shaping and burning clay, of domesticating animals and cultivating plants to form an agricultural safeguard against shortage of food, of transport and trade, and of all the multitudes of man's other economic activities, the art of winning and working metals has been more startling, and equally significant.

Aluminum and magnesium are metals of modern industry, the culmination to date of the skilled search for new metals and new uses of old metals. They are not metals of the past, but of the future. They may supplant some of the heavier metals which man so long used and which form the basis of his new air age. The air age and the aluminum age are synonymous.

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THE ALUMINUM INDUSTRY OF THE WESTERN HEMISPHERE

James E. Collier

THE aluminum industry of the Western Hemisphere is based on the bauxite of Arkansas, Surinam, and British Guiana, and the fuel, low-cost hydroelectric power, and other necessary materials of the United States and Canada. The industry is thus dependent on materials which are supplied by these widely separated parts of the Hemisphere, yet it is unified in the sense that little used in its production is derived from without the Hemisphere.

Bauxite: The Chief Aluminum Ore.—Bauxite, the principal ore from which aluminum is produced, is an hydrous aluminum oxide containing varying amounts of impurities, chiefly the oxides of silica, iron, and titanium. It is a mixture of several aluminum-bearing minerals and is a product of rock alteration, residual from subaerial weathering of aluminum-bearing rocks involving the solution and removal of constituents other than aluminum oxide. Such processes of weathering are considered to be active under the alternate wet and dry conditions and the relatively high temperatures of certain low latitude types of climate.

Aluminum is one of the most common and widespread of the elements of the earth's crust, being exceeded only by oxygen and silicon, and it occurs in many compounds in addition to those named. Although it is technically possible to obtain aluminum from several of the aluminum-bearing materials, none other than bauxite has proved a commercially successful aluminum ore. Alunite, leucite, anorthosite, and high alumina shale and clay are potential ores of aluminum. Only under attempted national self-sufficiency or similar conditions have any of these been used for the extraction of aluminum other than on an experimental basis. More or less successful attempts have been made to extract aluminum from a feldspar mineral which occurs in large quantities in the Kola Peninsula of Arctic Russia. The volcanic region of Italy has large quantities of leucite, but attempts to use this mineral to augment the somewhat limited bauxite reserves have resulted in reconversion of plants to the use of bauxite. The use of leucite in Japan has had similar results. Japan also has experimented with aluminum shales and clays, but the materials have not competed with imported bauxite. Probably the successful competition of any other material with bauxite will depend upon some by-product which can share the greater production costs. Both alunite and

leucite are considered adaptable to processes producing alumina (aluminum oxide) with potash as a by-product.

The use of bauxite as an ore from which essentially pure metallic aluminum can be produced has been economically practical only if the aluminum oxide content of the ore is approximately 50 per cent or greater. The use of lower grade ores has been possible by mixture with sufficiently higher grade ore to result in a mixture containing a minimum of 50 per cent alumina. Lower grade ores probably can be utilized in the future as technical improvements in refining make this feasible, or as a decline of the reserves of high grade bauxite requires. With the present known extensive deposits of the world there is little probability of exhaustion of high grade ores for a long time. However, the greater transportation costs of bauxite remote from the centers of consumption may at least partially offset the saving in production costs and enable lower grade domestic ore to be utilized.

Non-aluminum Uses of Bauxite.—Bauxite is not only the principal ore from which aluminum is extracted; it is also the basic raw material of several other industries. The aluminum industry of the United States normally consumes slightly less than one-half the domestic production and most of the imported bauxite. During the five-year period from 1934 to 1938 this amounted to an average annual consumption of 147,123 long tons of domestically produced ore plus 330,824 tons of imported ore. It is significant that the use of domestic bauxite for the manufacture of metallic aluminum in the United States has tended to decrease. Although our total bauxite production has increased, a larger and larger percentage of it has gone to the chemical, abrasive, and other non-aluminum industries, and imported ores supply more and more of our aluminum reduction requirements.

The abrasive industry is the largest non-metal consumer of bauxite in the United States and Canada (Figure 1). Twenty-nine per cent of the total United States production was used by this industry during the period from 1934 to 1938. For many purposes, abrasives of fused bauxite have supplanted the more rare natural corundum and emery. The Arkansas region supplies most of the bauxite consumed by the abrasive industry.

Certain chemical industries are important consumers of bauxite. The ore is used in the manufacture of aluminum salts which have value in dyeing, printing, tanning, paper manufacture, water purification, treatment of sewage, and for other purposes. About 22 per cent of the United States production of bauxite was consumed in these uses between 1934 and 1938. This met approximately one-half of the needs of

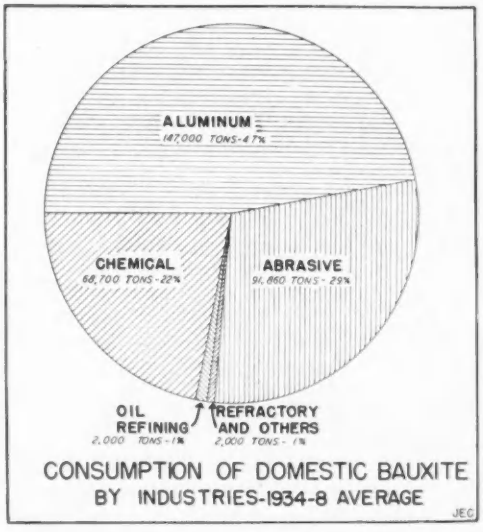

FIGURE 1.—Consumption of domestic bauxite by various industries in the United States, 1934–1938 average. Less than one-half of our total production is used for the manufacture of aluminum. Approximately one-half of the total is consumed by the abrasive and chemical industries. (Data from Minerals Yearbook.)

these industries and imported ore completed the annual requirements of more than 100,000 tons.

More than 2,000 tons of bauxite, about one per cent of the average annual production between 1934 and 1938, are consumed each year by the petroleum refining industry of the United States. Activated bauxite is used as a partial substitute for Fuller's earth and bleaching clay in the refining of crude petroleum. Its absorptive qualities are valuable in decolorizing and desulphurizing petroleum products.

Approximately one per cent of the bauxite produced annually in the United States is used in the manufacture of refractories. Furnace linings, and other refractories of bauxite or high-alumina clay are extremely resistant to deterioration at high temperatures. Substantial quantities of high-alumina refractories are required by the steel, glass, ship-building, and other industries.

Small quantities of bauxite produced in the United States and most of that imported from Greece (14,000 metric tons in 1937; 8,000 in 1938) are used in the manufacture of high-alumina cements. These cements harden rapidly and are relatively resistant to chemical attack. They therefore find valuable application in structures exposed to salt water or other chemicals, or where quick hardening is desirable. Fortifications and gun emplacements made of this type of cement are ready for use within 24 hours after pouring.

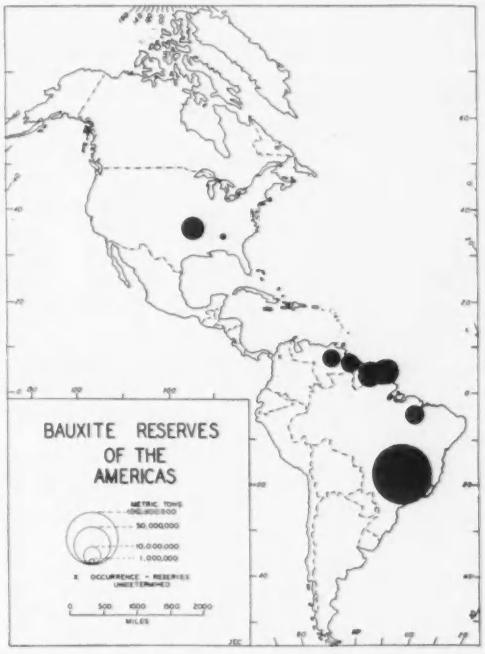

FIGURE 2.—Estimated bauxite reserves of the Western Hemisphere. Most of the bauxite resources of the Hemisphere are in South America. Brazil has larger reserves than any other country.

DISTRIBUTION OF BAUXITE DEPOSITS

The known bauxite deposits of the western hemisphere are in the United States, Surinam, British Guiana, Brazil, French Guiana, Colombia, Venezuela, Jamaica, and Haiti (Figure 2). Only those of the first four countries are being mined commercially, and Brazil has been producing only small amounts annually.

United States.—Bauxite is known to be present in Arkansas, Georgia, Alabama, Mississippi, Tennessee, and Virginia, and has been mined in all these except Mississippi. Immediately preceding the war Arkansas supplied 95 per cent of our domestic production and 43 or 44 per cent of our total bauxite requirements. Most of the remainder was imported from northern South America, chiefly Surinam. Arkansas also supplies practically all of the domestic ore used for aluminum reduction and for abrasives. Most of the bauxite mined in Alabama, Georgia, and Tennessee is used for chemical purposes, and for other non-metallic uses except abrasives.

The bauxite deposits of the United States occur in two areas, the Coastal Plain and the Appalachian Valley region

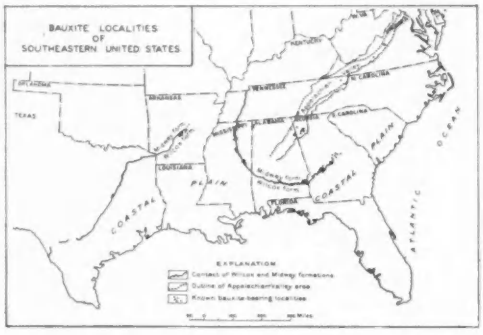

FIGURE 3.—Distribution of bauxite deposits in the United States. Occurrences are in the Coastal Plain region or in the Appalachian Valley region. (From U. S. Geol. Survey, 1941.)

(Figure 3). These are in two corresponding types of geologic locations. The deposits of the Coastal Plain of Arkansas, Mississippi, Alabama, and Georgia are nearly all at the contact of two early Tertiary sedimentary units, the Paleocene Midway group and the Eocene Wilcox group, or else on surfaces exposed at the close of Midway time. The greatest concentrations of bauxite have developed in central Arkansas where this contact overlaps two areas of intrusive nepheline syenite. Surficial alteration of the syenite produced irregular bodies of kaolinite, which by desilicification became bauxite. Elsewhere at the Midway-Wilcox contact clay seems to have been altered to produce the bauxite deposits.

The deposits of the Appalachian Valleys probably originated through the alteration of clay which accumulated in solution cavities in early Paleozoic cherty dolomites and limestones. Small deposits in the Coastal Plain of northwestern Alabama apparently formed from clay which accumulated in cavities or depressions in the Cretaceous Tuscaloosa formation resulting from solution of the underlying Mississippian limestones. Thus, their origin is similar to that of the bauxite of the Appalachian Valleys. In all cases the deposits presumably formed at the end of Midway time when climatic conditions favored rapid surficial alteration of the clays and kaolinite.

In central Arkansas, in Saline and Pulaski counties, the lenticular ore bodies flank two exposures of nepheline syenite. The deposits are thus in two areas, one just southeast of Little Rock and the other about 14 miles to the southwest (Figure 4). The latter area, southeast of the mining town of Bauxite, has furnished most of the ore produced.

The Coastal Plain deposits of Mississippi, Alabama, and Georgia describe a broad semicircle, convex toward the Gulf and Atlantic coasts. In Mississippi bauxite is distributed in groups of small separate deposits in a belt three to five miles wide describing an arc from north to southeast about 150 miles long. As a whole, the bauxite of Mississippi is low grade and not suited for aluminum reduction. None has yet been mined, but it may soon find use in some of the non-metallic industries.

The Alabama bauxite deposits lie in three widely separated areas; along the Midway-Wilcox contact in Barbour and Henry counties in southeastern Alabama, in five counties of the Appalachian Valleys of northeastern Alabama, and in Colbert County in the northwestern corner of the state. Production during the past decade has ranged from 11,000 to 17,000 tons annually. The Coastal Plain deposits occur in the form of lenses or "pockets" which are irregular in both outline and depth, and which contain good ore and clay intermixed. The deposits are generally small, ranging from a few feet to 50 feet in thickness and up to 100 feet in width and 200 feet in length. Mining, which has been active in this area since 1927 is from open cuts. The costs of mining vary greatly and depend on the proximity of shipping points

and roads as much as on the quality and quantity of the ore and its depth below the surface. According to its composition and quality, the ore has been used for the manufacture of aluminum and for chemical, abrasive, and refractory products. Its use has recently been restricted to the three last named types of products.

The bauxite of the Appalachian Valleys of Alabama occurs as irregular bodies associated with pockets in dolomites, although they do occur along somewhat regular lines following the outcrops of certain rocks. The ore bodies of the deposits of Colbert County, northwestern Alabama, range from a few feet to 75 feet in depth (thickness) and are generally overlain by one to five feet or more of surface soil and sand. The alumina content is generally too low (35 to 55 per cent) for the ore to be used for aluminum reduction. The deposits have not been mined and there seems little indication that they will be in the near future, since they are rather inaccessible, as well as low-grade and small in size.

Bauxite occurs in at least 10 counties in the Coastal Plain of central and southwestern Georgia and in six counties of the Appalachian Valley region of northwestern Georgia. The ore bodies of the Coastal Plain region are lenticular, varying from one or two feet up to ten feet in thickness. The quality of the ore

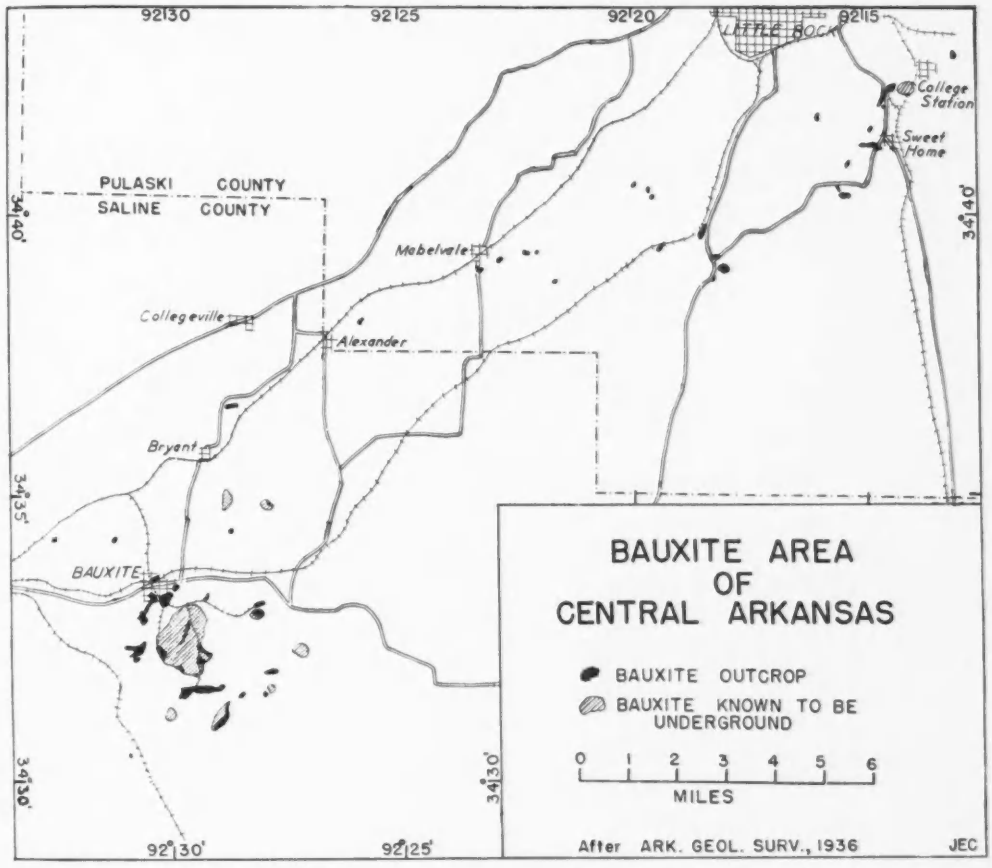

FIGURE 4.—The bauxite area of central Arkansas, showing the distribution of deposits and transportation facilities. (After Arkansas Geol. Surv., 1936.)

varies widely and in most cases it has a silica content too great for use in the production of metallic aluminum. The rather limited production has been used largely for chemical products. The bauxite of Floyd County, northwestern Georgia, was the first recognized in the United States. The deposits of this region are grouped in three areas; the Hermitage, Bobo, and Summerville districts.

The bauxite deposits of Tennessee occur in two widely separated areas; in the Appalachian Valley region of eastern Tennessee, and in Stewart County in the Western Highland Rim region. Analysis of the ore of the latter reveals an alumina content of 54 to 60 per cent, a rather high silica content, and an unusually low iron oxide content. No ore has been produced commercially from this area. The bauxite of the Appalachian Valley of eastern Tennessee occurs in two areas; in the vicinity of Chattanooga in the southeast, and near Elizabethtown in the northeast. The ore shipped from the Chattanooga district has been used in the chemical industries. The ore body of Carter County, northeastern Tennessee, is a large, irregular, deep pocket. Mining has been carried on from an open cut.

FIGURE 5.—The major bauxite districts of Surinam and British Guiana.

Bauxite deposits are found in Botetourt and Augusta counties within the Appalachian Valley region of Virginia. The ore of the deposits of Botetourt County occurs as scattered masses within clay and extends to depths of 15 to 30 feet. As a rule the ore is dark red and highly ferruginous. Two small deposits which occur in Augusta County are being worked at present. The ore is being shipped on a near-by railroad.

Bauxite Resources of the United States.—The bauxite reserves of the United States are not sufficient for the future use of the aluminum industry if production is maintained at its present level. Our known reserves, as of September 1, 1941, were 18,241,000 long tons, estimated on a "mined and dried" basis. This represents about 65 or 70 per cent, the approximate rate of recovery, of the actual raw bauxite in the deposits which have been well prospected. The rate of recovery varies from 50 to 75 per cent by underground methods to 85 or 90 per cent by open-pit methods. After mining there is an additional loss of approximately 15 per cent in weight through the process of drying which is customarily practiced before the ore is shipped from the mines. The above figure of reserves applies to bauxite containing 50 per cent or more aluminum oxide, the minimum requirement for the present process of aluminum reduction as well as for most non-metallic uses. An additional 10,787,000 tons of ore is estimated to exist, but it contains less than 50 per cent alumina and is not now considered to be of commercial grade (Table I). If the present processes are modified to make practical the use of these lower grade ores, our usable reserves will thus be extended.

In addition to these reliably esti-

mated reserves there are several hundred reported occurrences of ore which have not been adequately explored. Analyses of samples from these indicate the presence of bauxite of commercial grade. Little or no attempt has been made to develop these deposits and their tonnages cannot be accurately estimated. It is conservatively estimated, however, that the usable reserves of slightly more than eighteen million tons can be increased by as much as 10 per cent to include these undeveloped deposits. Thus, our total reserves may approximate 20,000,000 tons of ore usable by present standards. By the middle of 1942, exploration had revealed in 24 of these small deposits additional reserves of 256,000 short tons of ore which contains 50 per cent or more alumina.

Arkansas not only supplies 95 per cent of the domestically produced bauxite in the United States, but also has about 95 per cent of the reserves. Of the estimated reserves of 18,241,000 tons of commercially suitable ore, Arkansas has 17,533,000 tons (Table I). Georgia ranks second with 548,000 tons, while Alabama, Mississippi, Tennessee, and Virginia each has less than 100,000 tons of ore. Virginia has only 6,000 tons.

Bauxite in Surinam.—Surinam has some of the largest bauxite reserves of the Western Hemisphere. Reliable estimates of the total available ore have not been published, but a single ore body in one area is known to contain 10,000,000 tons and another 8,000,000 tons. The bauxite deposits are in northern Surinam on the Surinam and Cottica rivers and their tributaries. The ore bodies lie along the transition zone between the coastal lowlands and the foothill belt at the edge of the interior plateaus (Figure 5). Crushing and drying plants are located at Moengo on the Cottica River and at Paranam on the Surinam River. The Cottica River parallels the coast and flows westward into the Surinam River a few miles below Paramaribo. Bauxite is mined in the vicinity of Moengo, which is 100 miles by river from the sea, but only 20 miles by air. Bauxite for the Paranam crushing and drying plant is transported about four miles by narrow gauge railroad from mines in the Para Creek district.

The bauxite deposits of Surinam occur as flat-lying or undulating lenses or layers which, because they are more resistant to erosion than the enclosing clays and sands, often cap eminences or low hills as high as 120 feet above the surrounding level. This relation of deposits to topography aided the search for ore, since under the dense cover of

TABLE I

ESTIMATED BAUXITE RESERVES OF THE UNITED STATES, LONG TONS, BY STATES AND BY CLASSES OF ORE BASED ON ALUMINA AND SILICA CONTENT

(From U. S. Bur. Mines)

State	*Alumina 55% + Silica to 7%*	*Alumina 50–55% Silica 7–15%*	*Alumina 45–50% Silica 15–30%*	*Alumina 30–45% Silica over 30%*	*Total*
Arkansas	9,090,000	8,443,000	7,803,000	1,918,000	27,254,000
Alabama	16,000	79,000	33,000	230,000	358,000
Georgia	237,000	311,000	481,000	.....	1,029,000
Mississippi	.....	23,000	100,000	200,000	323,000
Tennessee	.....	36,000	22,000	.....	58,000
Virginia	.....	6,000	.....	.....	6,000
Total	9,343,000	8,898,000	8,439,000	2,348,000	29,028,000

vegetation an eminence is more easily seen than low ground. The ore bodies vary from small lenses to layers several hundred yards wide and several miles long. In thickness the ore varies from six to 25 feet. Overburden is up to 60 feet in thickness. At Moengo the ore body being mined averages 11 feet in thickness and has a maximum of 10 feet of overburden. The Paranam ore body is approximately one-third mile wide and two miles long. The reserves visible at Moengo are estimated at 10,000,000 tons. Those at Rorak on the Surinam River are estimated at 8,000,000 tons. A single ore body at Moengo was estimated to contain a 30 to 40 years' supply of ore.

Bauxite Deposits of British Guiana.—Bauxite occurs in northeastern British Guiana and is similar in occurrence and character to that of adjacent Surinam. Reserves are estimated at 10,000,000 tons. The ore districts lie from 60 to 80 miles from the coast, along the Demerara and Berbice rivers, both being northward flowing streams that lie east of the Essequibo River (Figure 5). Bauxite occurs in the vicinity of Wismar and Mackenzie, on opposite sides of the Demerara River about 64 miles from its mouth, and extends for about 10 miles upstream on both sides of the river. Other deposits include those of the Berbice River district which were discovered in 1938.

As in Surinam, the ore bodies of British Guiana are flatlying to undulating lenses or layers. The Three Friends deposit is a flat-lying lens averaging 18 feet in thickness. The overburden ranges from zero at the edges to 60 feet in the center. The better grade of ore contains about 60 per cent alumina. Between 15 and 20 per cent of the ore mined in recent years is a non-aluminum grade which has been used by the chemical industries of Canada, Great Britain, and the United States.

Bauxite in Brazil.—There are more than 80 bauxite deposits in Brazil, and reserves of ore are estimated as high as 150,000,000 tons. The deposits occur chiefly in two general regions: (1) in the states of Minas Gerais, Sao Paulo, Rio de Janeiro, and Espirito Santo in the southeast, and (2) in Para, Maranhao, and Bahia in the northeast (see Figures 2 and 6). Bauxite has also been reported in northern Brazil near the border of British Guiana, but little exploratory work has been done there. The plateau areas of the Brazilian highlands which have long been subject to sub-aerial erosion are favorable for the occurrence of bauxite, and considerable extension of the present known reserves is not unlikely.

The bauxite deposits of southeastern Brazil are estimated to total more than 130,000,000 tons in reserves and those of the northeastern region more than 10,000,000 tons. The largest reserves, estimated to total 120,000,000 tons, occur in the Pocos de Caldas plateau region of southwestern Minas Gerais and adjacent Sao Paulo. Most of Brazil's present production comes from

FIGURE 6.—Pertinent locations in southeastern Brazil. Bauxite deposits occur in the vicinity of Pocos de Caldas and Ouro Preto in Minas Gerais, and in the states of Sao Paulo, Espirito Santo, and Rio de Janeiro.

this district. The ore averages 60 per cent alumina, two per cent silica, and four per cent ferric oxide. Other fairly important deposits in Minas Gerais are in the vicinity of Ouro Preto, where three companies were operating in 1940. Reserves are estimated at 2,000,000 metric tons. Of less importance are deposits near Saranemha, Logoa do Bamba, and Moro do Cruziero, all in Minas Gerais. A recently discovered deposit in Sao Paulo, near the railroad from Pocos de Caldas to Santos, is reported to contain more than 5,000,000 tons of workable ore. In the Muqui deposits of the state of Espirito Santo are an estimated 1,000,000 tons of bauxite. Near Itatiaya in the state of Rio de Janeiro are some of the most advantageously located bauxite deposits of Brazil. An estimated 6,000,000 tons of high grade ore lie within easy access of the ports of Rio de Janeiro and Victoria. Deposits also occur near Entroncamento in the state of Rio de Janeiro.

In northeastern Brazil deposits on Trauhira Island are said to contain 10,000,000 tons of ore, and numerous others are known to exist, particularly along both sides of the Gurupy River which forms part of the boundary between the states of Maranhao and Para, and near Correntina and Barro do Mendes in the state of Bahia. Since the ore of Trauhira Island has a phosphate base, attempts are being made to develop a cheap process for the manufacture of alumina with phosphate as a by-product. If successful, this could supply the total Brazilian demand for phosphatic fertilizers.

Miscellaneous South American Deposits.—In addition to the deposits of Surinam, British Guiana, and Brazil, bauxite is found in Colombia, Venezuela, and French Guiana. A deposit from 12 to 20 feet thick extending over an area six by 12 miles is reported in the Department of Antioquia, Colombia. The deposit is on a good highway and a cursory examination indicates approximately equal transportation costs to Barranquilla and to Buenaventura. The cost of bauxite f. o. b. either of these ports, however, would probably exceed that of the more accessible ores of Surinam and British Guiana, so that the deposit may not be developed in the near future.

A bauxite deposit estimated to contain 10,000,000 tons of ore occurs on the Amacura River in northeastern Venezuela. A concession of 3,750 acres embracing 24 bauxite bearing areas has already been granted. The Amacura River is wide and deep enough to admit vessels drawing 15 to 20 feet of water. This would place the district on about an equal basis with those of Surinam and British Guiana if the quality of the ore is as good. The ore can be mined at an estimated cost of $1.00 (U. S.) per ton. This is almost twice the production cost of Brazilian ores, but the transportation cost would be considerably less than in Brazil.

French Guiana is geologically favorable for bauxite occurrence and considerable reserves may later be revealed. A survey of the resources of the area has been planned. Since France has deposits more than adequate for her own needs, little has been done toward development of bauxite mining in French Guiana. As long as that status continues, little can be expected toward development of the colonial deposits, unless by outside interests, such as American consumers.

BAUXITE PRODUCTION

Mining Methods.—Bauxite is mined by both open-pit and underground methods. If the overburden is not too great, the former produces ore at a

lower cost and is used where practical, but as the more easily accessible ore is removed, underground methods become necessary. In the United States, open-pit mining is prevalent in Alabama and Georgia, but in Arkansas and Tennessee both methods are used extensively, although strip mines still outnumber shaft and tunnel mines. In 1936 there were 18 open-pits and nine underground mines in Arkansas. In 1940 there were 18 open-pits and 13 underground mines, indicating an increase in subsurface mining practices. In 1939 an estimated 60 per cent of the total production came from underground mines and the remaining 40 per cent from open-pit mines. In the Guianas and in Brazil, mining is entirely by subsurface methods.

The mining method used in a particular district depends on the relation of the ore to the surface of the ground. Since bauxite is a product of rock weathering, its occurrence coincides with the present or a former land surface. When found at or near the present land surface, open-pit methods of mining are commonly practiced. Older, deeper occurrences can also be mined by stripping if the overburden is not too thick to permit its economic removal. The amount of overburden which can be removed depends upon its character and thickness, and on the quantity and quality of the ore thus made accessible. With deeper deposits, where conditions do not permit economic stripping, mining is by underground methods, chiefly by retreat caving.

The removal of overburden from surface or near-surface deposits involves no major problem beyond the cost of mining. The cover is in most cases unconsolidated, and it usually can be removed by power shovels without the aid of explosives. Since the ore bodies are commonly lenses or discontinuous masses there is ample space for storage of waste between them. Experience indicates that it is economical to remove from five to seven cubic yards of overburden to reach one cubic yard of bauxite. As much as 110 feet of overburden has been removed to reach 20 feet of bauxite, although stripping is not commonly employed if the overburden is more than 45 feet thick. Although the surface stripping type of mining presents no serious problem for modern methods, the size of the operations make the process slow. It may require six months to uncover a deposit of bauxite which can be mined in one month.

Because of the erratic nature of the size, shape and thickness of ore bodies, considerable risk is involved in mining. Deposits are commonly delineated by drill holes at the corners of 50- or 100-foot squares. Even when drilled at the closer interval, the grade of ore when mined may be found so altered between holes that a much smaller tonnage of high-grade ore is recovered than the prospect drilling indicated.

Mining by surface methods involves a smaller loss of ore than by underground methods. This loss, estimated at 10 to 15 per cent, results from the removal during stripping of erratic, vertical extensions of the ore into the overburden. Because of the size of the operations, these small, irregular extensions cannot always be economically recovered. Greater selection of ore is possible when it is uncovered by stripping than when underground mining is employed. However, the reduced quantity of high-grade ore thus recovered results in a greater mining cost per ton, since the entire cost of removing the overburden must be charged to the ore recovered.

If the overburden is greater than five times the thickness of the bauxite and a minimum of eight feet of ore is pres-

FIGURE 7.—Mining bauxite in Arkansas by surface method. The overlying material is stripped from the top of the ore (right center) which is then loaded by power shovels into cars for hauling to the crushing and drying plant. (Courtesy Aluminum Company of America.)

ent, underground mining by shaft or slope is usually employed. No economic limit can be set as to the minimum size of a deposit or to the maximum depth of a shaft, since the price, demand, actual cost of production, and transportation are the controlling factors.

In Arkansas the bauxite is commonly overlain directly or within a few feet by lignite beds of varying thickness. Moreover, in many places the upper portion of the bauxite itself is indurated by iron oxide or a siliceous cement. Either or both conditions usually means that it is possible to obtain a firm mine roof for underground operations. Except for the beds of lignite, however, the overburden of bauxite deposits is usually unconsolidated, and often it is difficult to mine a deep-seated ore body. By using underground methods it is usually possible to mine selectively, removing the high-grade ore and leaving the low-grade material untouched. A lower recovery rate results from the necessity of leaving ore in the mine roof and as pillars to support the roof. For this reason, from 25 per cent to as much as 50 per cent loss is not unusual in mining by this type of operation. Underground mining is also usually more expensive because of the necessity of hand-loading, timbering, pumping, ventilation, and other requisites of working underground.

The cost of mining bauxite deposits in the southeastern United States is somewhat greater than in Arkansas. Whereas the deposits of Arkansas are primarily of a residual blanket type, and individual occurrences are usually greater in their lateral than vertical dimensions, those of the other states have comparatively small lateral dimensions and frequently their vertical thickness is as great as or greater than the horizontal extent. This is a normal result of their mode of occurrence in solution cavities within dolomite or limestone beds. The problems of mining are quite different. It is true that for the same overburden removed the cost per ton of bauxite thus exposed is less when the vertical thickness is great. On the other hand, the stripped area must be greater than the extent of the ore body because of a tendency for the surrounding clays to slump and fall into the excavated pit. The excavation must be in the form of an inverted cone to provide a safe working slope. This excess of lateral stripping is of minor importance with the greater extent of the blanket deposits, but it may become a matter of major expense in mining the pocket-type deposit. The possibility of mining these small deposits by underground methods seems poor. There is little or no lignite above the ore bodies and the ore is for the most part too soft to form a safe roof. Furthermore, it is doubtful if the boundary walls would support themselves if the bauxite were removed. It would probably be too expensive to use timber for roof and wall support in mining a low-price commodity such as bauxite.

United States Production.—Production

of bauxite in the United States began in 1889 when 728 tons were mined in Georgia. In 1891 Alabama became a producer and in 1899 Arkansas entered the field. Annual production by this time has risen to 35,000 tons. Total domestic production remained under 100,000 tons annually until 1909, when 129,000 tons were mined (Figure 9). The output continued to rise until 1918, when an all-time high (up to 1940) of 605,721 tons were mined. Marked fluctuation characterized domestic production from 1918 until 1924, after which the annual output steadied at approximately 300,000 tons until the decline of the early 1930's. In 1932 the production of 96,349 tons was less than it had been since 1908. Production rose to 318,000 tons in 1938, to 381,330 tons in 1939, 445,498 tons in 1940, and 894,174 tons in 1941.

The bauxite deposits of Arkansas normally supply more than 95 per cent of our domestic production. The ore mined in Alabama, Georgia, and the other southeastern states has always been but a small part of our total output, and the annual tonnages have steadily declined. This has been due largely, if not entirely, to the quality of the ore, since most of the deposits of these states are high in iron and silica content. Because of this, the ore is not able to compete with higher grade Arkansas and imported ores for aluminum reduction. It is also handicapped for many of the non-metallic uses of bauxite. Recent reports, however, indicate that one of the newer aluminum producing companies of the United States plans to utilize by an improved process some of the low-grade, siliceous ores of the south.

FIGURE 8.—Mining bauxite underground near Bauxite, Arkansas. The ore is loosened by explosives and is loaded by hand into cars which transport it to the crushing and drying plant on the surface. Fuses attached to explosive charges in the mine roof and walls are discernible. (Courtesy Aluminum Company of America.)

The number of mines in the different bauxite producing states is indicative of their relative importance in bauxite mining. Seven mining companies operate 31 mines in Arkansas. There are four mines in Alabama and four in Georgia. Mississippi produced a small tonnage of ore for the first time in 1940.

Bauxite Production in Surinam.—Bauxite production in Surinam began in 1922 and, except for a slump during the latter half of the 1930's, has increased steadily since that time. By 1940 Surinam was the leading producer in the Western Hemisphere and second only to France among world producers. France and Hungary averaged a greater production than Surinam from 1934 to 1938. The average annual production in Surinam during this five-year period was 279,000 tons. The output rose from 115,184 metric tons in 1934 to 511,719 in 1939, and 615,434 in 1940. It probably has continued to increase since the latter date, but not as rapidly as during the period immediately preceding it. Practically all of Surinam's bauxite is exported to the United States.

A major advantage of Surinam for exporting bauxite lies in the proximity of the deposits to the coast. This factor has been second only to the quality of the ore in favoring the development

of bauxite mining and exportation. Sand and mud bars at the mouths of the rivers limit the draft of vessels to 17 feet. Beyond these bars the large rivers are deep enough to permit boats to penetrate well into the interior. The ore need be transported only short distances by rail to crushing and drying plants which are on the navigable rivers. Ocean transportation is somewhat handicapped by the shallow mouths, and also the winding character of the rivers which limit to 340 feet the length of boats reaching the crushing and drying plants. Shipment is therefore necessarily by small steamers at somewhat higher rates than ocean freight costs for European bauxites which can be shipped to the United States and Canada on larger vessels and at ballast-freight rates. This is not enough of a handicap to counteract the advantage of the proximity of the ore to the United States and its high quality which is favored in American markets.

The original development of the bauxite districts of Surinam was difficult because of the frequent tropical rains during the rainy season, the difficulty of securing skilled labor, and the necessity of importing practically all materials needed. Power for the crushing plants is supplied by Diesel engines using imported fuel, and the drying kilns are heated by imported oil. Construction of roads and railroads has been difficult in the lowland portion because of the low, swampy nature of much of the terrain and because of the many streams to be crossed.

Bauxite Production in British Guiana. The bauxite of British Guiana was discovered in 1910 and development began in 1915. Handicapped by the first World War, production was of little consequence prior to 1923, when 136,000 metric tons were mined. Except for a slump to approximately 50,000 tons annually during the first half of the 1930's, annual production has approximated 200,000 tons until the present period in which it has risen from 231,000 tons in 1936 to an estimated 600,000 tons in 1941. In recent years almost three-fourths of the British Guiana ore has been exported to Canada, about one-fifth to the United States, and the remainder to Great Britain.

The Demerara River of British Guiana is navigable by ocean-going vessels of not more than 17 feet draft as far as Mackenzie (Figure 5), which is the site of the bauxite crushing, washing and drying plants of this district. The ore of the Three Friends district farther upstream is transported by narrow-gauge railroad to this point. At Mackenzie the ore is crushed, washed, and dried, removing most of the intermixed clay and absorbed water. This concentrating process reduces the weight of the ore by approximately one-fourth. Dried ore from the Berbice River district is barged to Everton, at the head of ocean navigation, for transshipment to ocean-going vessels.

A problem of the disposal of waste washed from bauxite at Mackenzie results from the tidal character of the

FIGURE 9.—At Bauxite, Arkansas, the ore is transported from the mines to the crushing and drying plant in the background over narrow gauge railroad. (Courtesy Aluminum Company of America.)

Demerara River. Silting and obstruction of its channel results if the stream is overloaded. The problem has been solved by the construction of a dam, creating a settling basin on the flood plain. Bauxite washings are discharged into this basin and the water is withdrawn after the silt settles to the bottom of the pond.

As is the case also with respect to Surinam bauxite, the low cost of mining and the proximity of the deposits to ocean navigation enables British Guiana producers to profitably export bauxite. The size of vessels which can reach the processing plants is limited by the 17-foot depth of the river mouths and this increases slightly the freight rates over those of ore shipped from deep-water European ports, chiefly in France, Greece, and Yugoslavia. The high quality of the ore, its low mining costs, and American and Canadian commercial interests in its production have enabled British Guiana ore to compete with other producers in the American markets.

Brazil's Bauxite Production.—The development of bauxite mining in Brazil has been handicapped by the lack of an adequate domestic market and by the difficulties of export. Domestic consumption which began with about 1,000 tons in 1936 had risen to 3,000 tons in 1938, and is probably somewhat more than that at the present time. Exports have generally been less than 20,000 tons annually, all of which until 1941 have gone to Argentina for the manufacture of aluminum sulfate. During the first nine months of 1941 Brazil exported 2,600 metric tons of bauxite to the United States.

There is no aluminum reduction industry in Brazil and domestic consumption of bauxite is limited to the manufacture of aluminum sulfate, used in water purification, and to the production of abrasives and refractory materials. The small demand for these products and the limited capacity of plants using bauxite as a raw material precludes any appreciable increase in domestic consumption in the near future. The aluminum requirements of Brazil are not large enough to require large quantities of bauxite, even if the demand were met by domestic production. Imports of aluminum manufactures and semi-manufactures averaged about 1,500 metric tons annually between 1935 and 1940, and approximately 4,000 tons of aluminum sulfate were imported annually during that period. Imports in 1940 were 1,638 metric tons of aluminum in the form of bars, sheets, and wire, and 122 tons of manufactured aluminum products. At the most, less than 10,000 tons of bauxite would be required to produce this quantity of aluminum. Moreover, Brazilian aluminum production would be handicapped by the necessity of importing most of the raw materials other than bauxite, such as soda ash, coke, tar and pitch, coal and gas.

Exportation of bauxite to aluminum producing countries is not commercially practical under the existing conditions in Brazil. The low cost of mining by the prevalent surface methods is offset by high freight and loading costs resulting from transportation difficulties. Although there are railroads near most of the bauxite deposits, transportation is handicapped by the shortage of rolling stock and the differences in gauge of track between the deposits and the coast. The logical outlet for the ore from the Pocos de Caldas plateau area is the port of Santos. Shipping by this route involves a change of railroad gauge at Campinas (Figure 6). Furthermore, the lack of enough freight cars limits the possible annual shipments to 50,000 tons, while four times that amount could be produced at the

mines. A similar condition exists in the vicinity of Ouro Preto. Ore shipments must be reloaded from one gauge railroad to another at Lafayette and must also be transferred from 20-ton to 45-ton freight cars. In a similar manner, shipment from the Muqui deposits of Espirito Santo is limited to about 6,000 tons annually. With increased capacity of the railroads, exports can be expected to increase several fold.

The cost of mining bauxite in Brazil is approximately $0.55 per ton, and of crushing and drying the ore $2.42 per ton. The cost of transportation increases this so that the selling price must be from $8.80 to $11.00 per ton f. o. b. Santos and $6.60 to $9.90 per ton f. o. b. Rio de Janeiro. The average value of bauxite shipped by mine producers in the United States was $5.77 in 1939 and $5.93 in 1940. The market quotations of French, Greek, and Dalmatian ores in 1940 was between $7.00 and $8.00 per ton, C. i. f. Atlantic ports.

The reduction of ocean freight rates also seems essential to foreign marketing of Brazilian bauxite. The rate was $5.00 per ton to United States ports in 1940. Since the market price in the United States is not over $6.00 per ton, shipments from Brazil apparently depend on freight rates of not more than $5.00 per ton, unless the market price is increased to absorb the higher freight charges.

TRADE IN BAUXITE

The United States and Canada are the only important consumers of bauxite in the Western Hemisphere. Canada produces no ore, but imports her total supply; the bulk of it from British Guiana. The United States has for the past quarter-century depended more and more on imported bauxite. Since 1930, although steadily increasing, domestic production has supplied a smaller and smaller percentage of our domestic requirements (Figures 9 and 12). Most of the United States' imports are derived from Surinam.

Surinam and British Guiana are the major bauxite exporting countries of the Western Hemisphere. Except for small quantities of ore which normally move from British Guiana to the United Kingdom, the production of both Surinam and British Guiana is consumed in either the United States or Canada. These exports to the United Kingdom average only about 15,000 tons a year, and they decreased from 78,900 metric tons in 1935 to 24,000 tons in 1938 and 12,000 in 1939. This indicates the growing market in the United States and Canada, especially the latter, for British Guiana ores; and the increased dependence of the United Kingdom on European ores. In recent years Brazil has exported bauxite to Argentina and has consumed some domestically, but only in small amounts and that not for aluminum reduction.

There has been an exchange of position of the United States and Canada as consumers of British Guiana bauxite. Except during the 1930–1935 decline accompanying the world-wide slump in bauxite markets, the production of British Guiana has increased steadily since 1923. Exports to the United States, however, have decreased from 133,000 tons in 1931 to 91,000 in 1936 and 30,000 tons in 1939. The exports to Canada meanwhile increased from 25,000 tons in 1935 to 169,000 in 1936, to 400,000 tons in 1939 and 900,000 in 1941. This change in markets accompanied the development of Canadian aluminum production in the St. Lawrence valley and was favored by the all-water route from the ore deposits to reduction plants.

Bauxite mining in Surinam is largely in the hands of companies associated

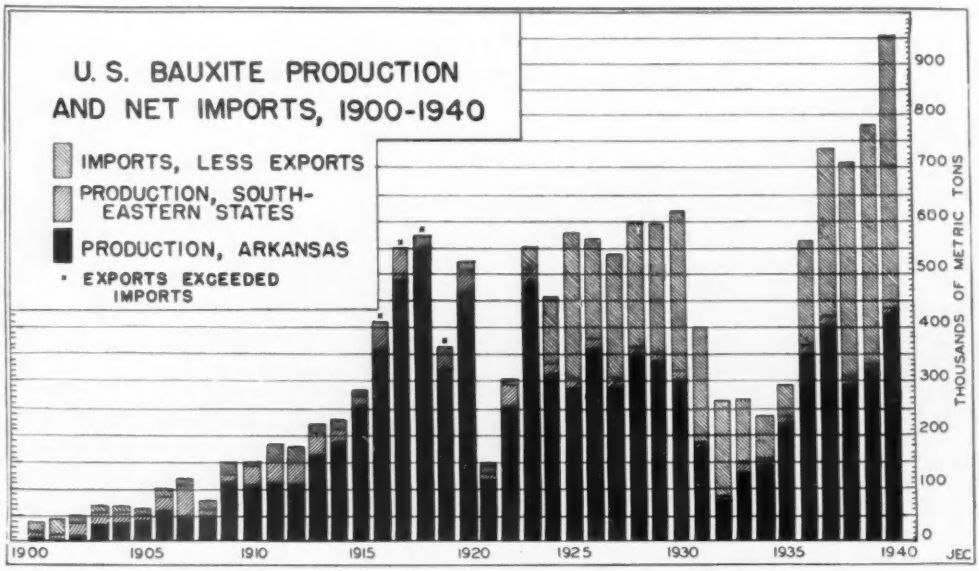

FIGURE 10.—Bauxite production in Arkansas, in the remainder of the United States, and net imports (imports minus exports), 1900–1940. The total length of each column indicates the apparent consumption (Data from Minerals Yearbook.)

with American consumers and all the ore is exported to the United States. From the beginning of mining in 1922 there has been a steadily increasing flow of ore from Surinam to the United States (except during a decline accompanying the world-wide decline in the first half of the 1930's). From 271,000 tons in 1930 exports decreased to 100,000 tons in 1934. They then rose to 111,000 tons in 1935, to 217,000 tons in 1936, 400,000 in 1937, 596,000 in 1940 and more than 1,000,000 tons in 1941.

In addition to our imports from Surinam and British Guiana, mostly from the former, the United States has imported small quantities of bauxite from other producers. The tonnages, however, are insignificant and the bauxite is used chiefly for certain non-aluminum purposes, such as alumina cements and chemicals. Our imports from France were 21,000 tons in 1930, about 5,000 tons annually from 1931 to 1934, 10,000 tons in 1937 and 5,000 tons in 1939. From Greece we imported 15,000 tons in 1937 and 8,000 tons in 1938. Greece is a recent producer of bauxite, and her relation to the United States cannot yet be determined. Our imports in 1937 and 1938 were only 10 to 12 per cent of her production, and Germany and the United Kingdom were her major markets. Disruption of European markets may account for the exports to the United States during those years. The position of the Netherlands Indies with respect to United States markets was similar to that of Greece. Our imports were 29 tons in 1939 and 13,630 tons in 1940, but Japan and Germany constituted her major markets.

MANUFACTURE OF ALUMINA AND ALUMINUM

Locations of Bauxite Processing Plants. Bauxite is usually washed to remove the clay with which it is commonly intermixed. It is then dried in rotary kilns to remove some of the absorbed water. The presence of clay in later

stages of the refining process results in the loss of materials and reduces the per cent of aluminum recovery. Both washing and drying are designed to concentrate and purify the ore and to reduce its weight. They are therefore carried out near the bauxite mines. Washing and drying plants are located at Bauxite, Arkansas, and elsewhere near the deposits of the United States. The ore from Surinam is washed and dried at plants at Moengo and Paranam (Figure 5) on the Cottica and Surinam rivers, respectively. The ore for the Moengo plant is mined in the immediate vicinity and that for the Paranam plant is transported by narrow gauge railroad from the mines about four miles away. In British Guiana crushing and drying is done at Mackenzie, with ore transported by narrow gauge railroad from the mines farther up the Demerara River. Bauxite from the newly developed Berbice River district is dried at the mines and barged downstream to Everton, where it is loaded into ocean-going vessels.

Washing and drying plants are located near bauxite deposits unless the conditions are modified by transportation facilities. Those of the United States are in the immediate area of the ore deposits and the ore is shipped by rail. The plants at Paranam and Mackenzie are at the head of navigation of the streams near the deposits, and the ore is transported short distances from the mines. The drying plant for the Berbice River bauxite is near the mines and the ore is shipped to the head of navigation. At the Moengo operations the Cottica River is navigable to the deposits and the plant location coincides with both occurrence of bauxite and navigable water.

In drying bauxite, the fuel and power requirements constitute an important but not critical location factor. The costs are nowhere great enough to affect seriously the location of crushing and drying operations. In Arkansas, natural gas is used extensively to fire the rotary kilns and about 22,000 cubic feet are required to dry the four to five tons of bauxite required to produce one ton of aluminum. Purchased electrical power is used for crushing the ore and for other operations in handling the

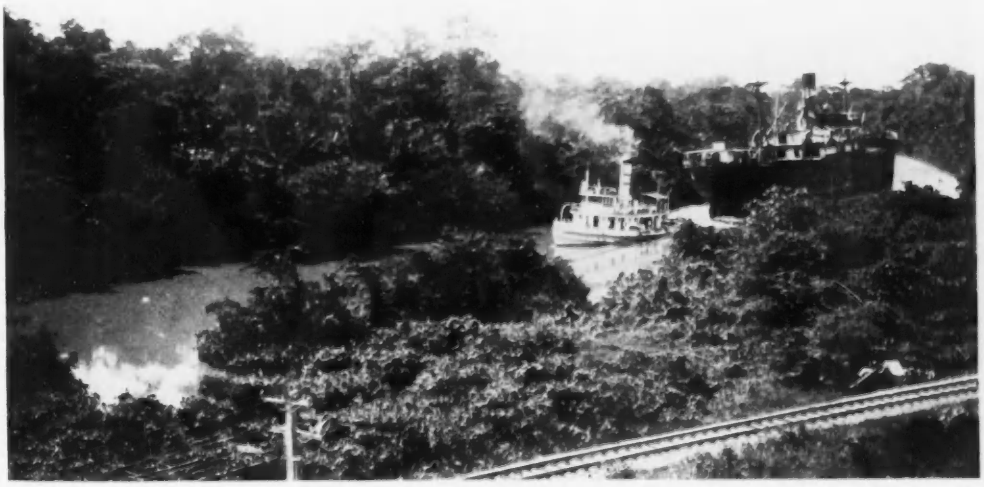

FIGURE 11.—An ore boat pulled by a tug on the Cottica River, near Moengo, Surinam. The railroad in the foreground connects bauxite mines with the crushing and drying plant at Moengo. (Courtesy Aluminum Company of America.)

bauxite. From 5,000 to 6,000 kilowatt hours of electrical energy are needed to process one ton of bauxite. In 1939 fuels used in processing bauxite cost $188,000 and represented 14 per cent of the principal expenses of the industry. This is a considerable increase over the nine per cent in 1919 and 10 per cent in 1929. Another striking change in this respect is the source of electric power. In 1919 all electric motors were driven by energy generated by the operating companies; in 1929 and 1939 all electric motors were driven by purchased electric energy.

The bauxite of British Guiana is crushed and dried with energy and heat derived from imported oil. Potential water power in both Surinam and British Guiana leads to the possibility of locally supplying some of the power requirements in the future. Falls exist in many of the rivers where they flow from the interior plateau down upon the coastal lowland.

After bauxite is washed and dried it is shipped to alumina plants where the iron, silica, and other impurities are removed, and the chemically combined water is separated from the aluminum hydrate by calcining. Plants for this operation in the United States are located at East St. Louis, Ill., Mobile, Ala., Lister, Ala., Hurricane Creek, Ark., and Baton Rouge, La. (Figure 13). In Canada alumina is manufactured at Arvida, Quebec.

The Aluminum Reduction Process.—The usual method of removing iron, silica, and other impurities from bauxite and of producing pure alumina is by a chemical method known as the Bayer process. In this process, finely ground bauxite is mixed with a sodium hydroxide solution which dissolves the aluminum oxide and can be filtered from the unaffected impurities of the ore. Aluminum hydrate is precipitated from this solution and is calcined (heated to very high temperatures, usually in rotary kilns) to drive off the chemically combined water, producing substantially pure aluminum oxide. The preparation of alumina from bauxite is a major chemical industry within itself.

The process of separating the oxygen and aluminum of alumina consists of dissolving the alumina in molten cryolite and passing an electric current through the fused mass to electrolytically separate the aluminum. This is accomplished in an electrolytic cell constructed of a steel box lined with refractory material of low thermal and electrical conductivity and into which is rammed a heavy carbon lining. Alumina and cryolite are placed in this cell and fused by heating. Carbon electrodes are suspended from bus bars above the cells and carry the electrical current into the electrolyte. The carbon lining serves as the cathode. The electric current serves two purposes. It keeps the electrolytic bath liquid by the generation of heat, and it causes the separation of the oxygen and aluminum of alumina. The oxygen goes to the carbon anode and burns, consuming the carbon in the process. The aluminum is deposited on the bottom of the cell, from which it is periodically tapped through an opening for that purpose. United States plants for this aluminum reduction process are located at Massena, Niagara Falls, and Maspeth, N. Y.; Burlington, N. J.; Badin, N. C.; Alcoa, Tenn.; Lister, Ala.; Jones Mills, Ark.; Longview, Vancouver, Tacoma, and Mead, Wash.; Troutdale, Ore.; and Modesto and Los Angeles, Calif. (Figure 13).

Materials Required.—To produce one ton of alumina, from two to three tons of bauxite (depending on quality), two tons of soda ash, and an abundant supply of water are required. To produce

one ton of aluminum requires about two tons of alumina, one-half ton of carbon electrodes, a small amount of cryolite or other fluoride salts, and three to four horsepower years (24,000 to 25,000 kilowatt hours) of electrical energy. The problems of assembling these raw materials are of major importance in the location of plants.

The three most important of these materials are bauxite, coal, and electrical energy. None of the industrial regions of the world have all three in close proximity. In the Western Hemisphere, the United States and Brazil possess all three, but they are separated by considerable distances and in the latter country by poor transportation facilities as well. Of the three, coal and bauxite can be economically transported considerable distances; electrical energy cannot, so the final reduction process which requires large quantities of cheap electricity is almost invariably carried out near hydroelectric power sites.

Most of the world's bauxite locations are not near coal. The tendency seems to be for the bauxite to be concentrated by washing to remove clay and drying to remove some of the water at or near the mines, and then to be shipped to, or toward, coal; providing the factor of electrical power and cheap transportation combined do not result in both bauxite and coal being transported to power sites, as is done in Canada. The requirements of soda ash and water are not of major importance, since relatively small quantities of the former are required and since the latter is relatively widespread in its occurrence. The question of labor supply should not be overlooked, but it suffices to say that it is not a deciding factor, since the requirements are low and constitute only a minor part of the cost of production.

Location of Alumina Plants.—Alumina plants are generally oriented toward a source of coal, with transportation in most instances determining the more specific aspects of location. For many years all of the alumina consumed in the United States was produced at a plant at East St. Louis, Illinois. This location is intermediate between the bauxite of central Arkansas and the coal of Illinois and adjacent states. Both bauxite and coal are transported only short distances to the plant. The location on the Mississippi River also permits relatively cheap barge transportation of bauxite from Surinam and British Guiana after transshipment from ocean-going vessels at New Orleans. The location is also favorable with respect to shipment of alumina to the aluminum reduction plants which are located near hydroelectric power sites in the southern Appalachians and in the St. Lawrence River valley.

The influence of transportation can be seen in the location of the newer alumina plants. Cheap water transportation was one of the major reasons for the development of the aluminum industry in the St. Lawrence valley in Canada, and for the location of alumina plants at Mobile, Alabama and Baton Rouge, Louisiana. Both of the latter are easily accessible to ore boats which bring bauxite from Surinam or from British Guiana. Mobile is also conveniently located for use of Alabama coal, and the Baton Rouge coal requirements can be met cheaply with barge shipments down the Mississippi River or by rail from the southern Appalachian Field. The alumina is shipped by rail to reduction plants in the east, or by water to reduction plants near the west coast.

The Canadian aluminum industry was begun on the basis of cheap hydroelectric power at Shawinigan Falls, Quebec, on the St. Maurice River and

FIGURE 12.—Bauxite loading station on the Cottica River at Moengo. The ore is transported from the mines by narrow-gauge railroad (right foreground) and is crushed, washed, and dried before shipment by boat (as in Figure 11) to alumina plants in the United States. Moengo has a population of about 2,000, most of whom are employed by Surinaamsche Bauxite Maatschappij, the mining company. In the right background of the picture are the homes of miners and workmen. (Courtesy Aluminum Company of America.)

at Arvida on the Saguenay River. Alumina was first imported from the East St. Louis plant, but it soon was manufactured at plants established at Shawinigan Falls and at Arvida. Both consume bauxite imported by water directly from British Guiana.

Still more recently, an alumina plant has been established in the Arkansas bauxite region and one in northwestern Alabama. The former substitutes natural gas from the southern Arkansas field for coal and has the advantage of close proximity to the bauxite mines, removing the necessity of transporting bauxite. The northwestern Alabama alumina plant at Listerhill uses coal from the Southern Appalachian Field. Part of the alumina is reduced to aluminum at a plant at the same location, using electricity purchased from the Tennessee Valley Authority, and part of it is transported via Panama Canal to Longview, Washington, where electricity from the Bonneville power project is used for its reduction.

Location of Aluminum Reduction Plants.—The cost of electrical power, which is one of the large items in the cost of aluminum production, is probably the most influential of the location factors of the industry. The first aluminum reduction plant in the United States was established at Pittsburgh, Penna., in 1888, using coal to generate electricity for its operation. In 1891 it was moved to New Kensington, Penna., and converted to the use of gas, which was cheaper. In 1895 the reduction plant was moved to Niagara Falls and became one of the first consumers of the hydroelectric power developed at that site, since this was cheaper than either coal or gas. Because of the demands of other industries for this power, Niagara Falls has not proved the most favorable site. Subsequent development of aluminum production occurred at Massena, N. Y., Alcoa, Tenn., and Badin, N. C., sites where there has been little or no competition for the use of the electric power and where the costs are therefore lower. In fact, the leading aluminum producing

company in the United States (and until 1941 the only producer) has developed sites and produced most of its own power. Only in recent years have public power projects been the source of much electricity consumed in aluminum reduction. The power consumed by the aluminum industry of the United States in 1940 constituted about eight per cent of the total consumption of electrical energy for both public and industrial use.

The primary requisite for commercial production of aluminum from aluminum oxide by the electrolytic process is a source of abundant, low-cost electricity, hence, most aluminum reduction plants derive electricity from hydroelectric power plants. Large deposits of lignite which can be mined at low cost, together with the absence of cheap water power, have led to the use of electricity generated from lignite for aluminum reduction in some of the plants in Germany. Economic nationalism encouraged this, and it is said to produce aluminum at a cost no greater than by the use of water power. The aluminum industry as a whole has expanded more rapidly, however, in countries such as Norway and Canada which possess abundant water power near ocean shipping and which are not too remote from the aluminum consuming countries of the world. It has been stated that the aluminum industry cannot afford to use power costing more than $10 to $15 per horsepower year. Except under unusual circumstances, this eliminates all fuel-fired installations, and many of the available water power installations, since near-by cities and industrial consumers can usually pay more than the maximum for economical aluminum reduction. The aluminum industry is therefore driven to locations at which power can be developed cheaply and cannot be sold at a higher price than the industry can afford. The classic example of cheap power is supplied by the Rjukan development in Norway where water from a mountain lake drops 2,000 feet through eight or more power stations on its way to the sea. This power is reportedly produced at a cost of less than $3 per horsepower year, well under the maximum considered economical for the aluminum industry.

For economical aluminum production electrical power must not only be available at low cost, but service must not be interrupted. "Off-peak" power, even at a very low cost, is not attractive to the aluminum industry. When the flow of power to the electrolytic cell is interrupted, the fused bath solidifies and not only does a loss of materials result, but the cell produces low-grade metal for the first few weeks of new operations.

In the United States and Canada, such streams as the Saguenay, St. Maurice, and Grass rivers, tributary to the St. Lawrence, and the Little Tennessee and Yadkin rivers of the southern Appalachians meet the requirements of the aluminum industry. In recent years the abundant power of the Tennessee and Columbia rivers has been used for the reduction of aluminum. In these instances, although there are many other consumers of the power, its abundance makes it low-cost and economical for the production of aluminum.

Carbon may be considered a raw material required for aluminum reduction, since a half-ton or more of carbon electrodes are consumed in the production of one ton of metallic aluminum. These electrodes are made from a mixture of carbon and a binding agent. Petroleum coke, residual from petroleum distillation, or pitch coke, a product of the destructive distillation of pitch, supply the required carbon. Since any residue left after the electrode burns becomes mixed with the electrolytic bath

and may appear as an impurity in the aluminum ingots, petroleum coke is commonly preferred because of its lower ash content. Anthracite coal may be used, but it has a higher ash content than either pitch or petroleum coke. Most of the aluminum reduction plants produce their own electrodes.

Cryolite, a sodium aluminum fluoride found in commercial quantities in its natural state only in Greenland, is another of the raw materials required for aluminum reduction. Alumina is dissolved in a cryolite bath for reduction in the electrolytic cell. Natural cryolite was formerly used exclusively, but most of the requirements are now met with synthetic cryolite. Hydrofluoric acid, soda, and alumina are required materials for its manufacture. Most of the fluorine is obtained from fluor-spar mined in the Kentucky–Illinois district.

ALUMINUM PRODUCTION

The first commercial production of aluminum by the electrolytic process, discovered in 1886, marked the beginning of one of the major industries of the United States. The output was at first only about 50 pounds per day, and many technical and economic difficulties handicapped the infant industry. Since one of the outstanding qualities of aluminum is its light weight, its full development necessarily awaited the development of uses demanding light weight metals. Another major factor in the consumption of aluminum has been its cost. Difficulties of production, the small scale of the industry, and numerous other factors led to a high production cost in early aluminum production. The cost of crude aluminum per pound was $17 in 1859, when the world's production by a chemical process was two tons. Following the discovery of the electro-chemical process which is still in use, the price was reduced to $5 per pound. The selling price by 1891 was 50 cents a pound, and by 1899 it was down to 33 cents. During the first World War, when the industry reached its first major development as a modern industry, the price rose to 37 cents per pound, but it subsequently dropped to 20 cents and now sells at about 15 cents per pound.

Development of the Industry.—The progress in the development of the aluminum industry in the United States may be divided into six transition periods. The *first* of these (1882–1886)

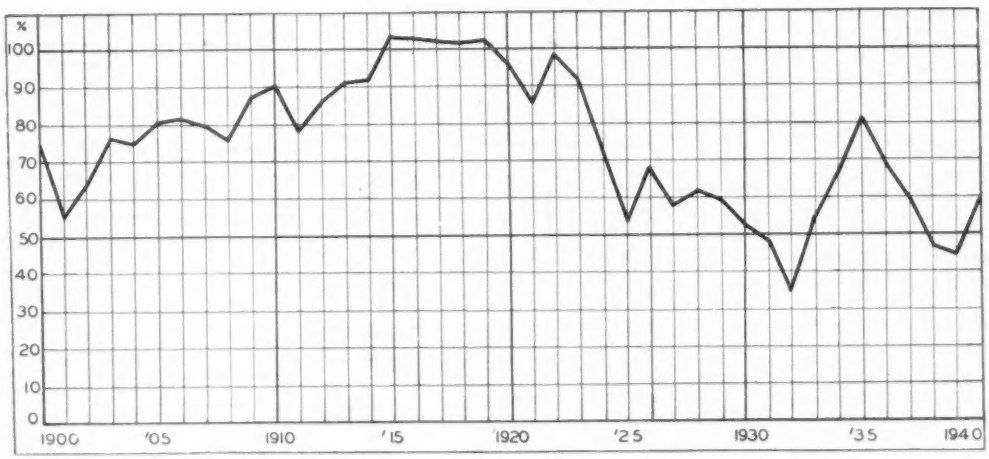

FIGURE 13.—Graph of the per cent of the total bauxite requirements of the United States which is supplied by domestic production, 1900–1940. (Data from Minerals Yearbook.)

includes the period from the first production of the metal in the United States in 1882 or 1883 to the development of the electrolytic reduction process in 1886. During this period metallic aluminum was produced by expensive chemical processes, and with the improvements of these processes it changed from a rare, precious metal to a more common metal adapted to many uses.

The *second* period (1886–1898) in the progress of the aluminum industry dated from the development of the cheap commercial process for the electro-metallurgical reduction in 1886 simultaneously and independently by Charles Martin Hall in the United States and Paul L. T. Herault in France. The Hall-Herault electrolytic separation of aluminum and oxygen became the standard process and is little changed to the present time. Producers of aluminum from the inception of this process to the end of this period were engaged in the solution of technical problems involved in its operation, in raising operating capital, and in finding outlets for their product. The difficulties of the reduction process had been largely overcome and the industrial importance of the metal established by 1898, the end of this period.

The *third* period (1898–1908) extended from the satisfactory solution of the problems of commercial production of aluminum and the establishment of its importance to the beginning of large-scale manufacture of automobiles in 1908. Producers were engaged in extending plant facilities, acquiring bauxite reserves, finding new outlets for the metal, increasing its applications, and in establishing themselves in the electrical field.

A *fourth* period (1908–1918) began with the large-scale manufacture of automobiles and extended to the end of the first World War. It was marked by a more widespread use of aluminum in the automotive and electrical industries than before. The war led to great interest in the properties and uses of aluminum, especially of the aluminum alloys. This period marked a ten-fold increase in the production in the United States and the establishment of the industry in Canada.

The *fifth* period, from 1918 to about 1940, witnessed a revolution in the development and uses of the metal and its light alloys, especially in the transportation industry. Markets were broadened and many new uses established. The properties of the new alloys far exceeded those of earlier periods.

A current period, initiated by the second World War, has been marked by new and extended uses of the metal and its alloys, by rapid depletion of conveniently available bauxite resources, by partially successful search for im-

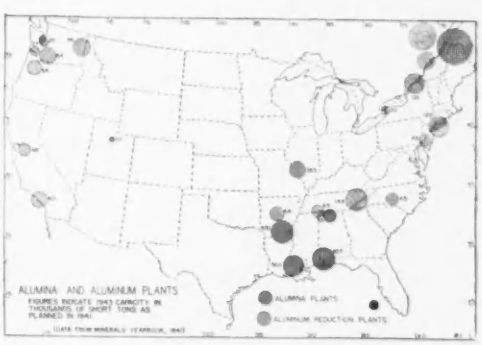

FIGURE 14.—Distribution of alumina and aluminum manufacturing plants in the United States and Canada, 1941. Alumina plants are at East St. Louis, Ill. (383,000 tons annual capacity); Mobile (657,000 tons) and Lister (95,000 tons), Ala.; Hurricane Creek, Ark. (650,000 tons); Baton Rouge, La. (500,000); and at Arvida, Quebec. Aluminum reduction plants are at Massena (121,000 tons), Niagara Falls (20,000), and Maspeth (128,000), New York; Burlington, N. J. (48,000); Badin, N. C. (45,000); Alcoa, Tenn. (149,000); Lister, Ala. (45,000); Jones Mills, Ark. (64,000); Longview (27,000), Vancouver (84,000), Tacoma (20,000), and Mead (96,000), Wash.; Troutdale, Ore. (64,000); and at Modesto (48,000) and Los Angeles (80,000), Calif. Canadian aluminum reduction plants are at Arvida and Shawinigan Falls, Quebec.

provements in the reduction process which would permit the use of lower grade bauxite, and by intensive experimentation with processes designed to use non-bauxitic ores. It has been accompanied by phenomenal expansion of our production capacity to meet wartime needs and an annual production rate equivalent to our total production prior to 1938.

Production of aluminum in the United States increased gradually until 1912, and then rose rapidly to its first major peak in 1918, when 100,000 metric tons were produced (Figure 15). Following World War I, a slump to 25,000 tons marked the first important decline in production. Within two years, however, the industry had regained an annual output of 65,000 tons, where it remained until its second peak of more than 100,000 tons in 1929 and 1930. The depression years which followed witnessed another decline to a low of 33,000 tons in 1934. Then followed a steady increase which has continued to the present when the rate of production is the greatest in history. Nearly 190,000 tons were produced in 1940, and 309,000 tons in 1941. The production rate at the end of 1941 was 380,000 tons, and it was expected to double or possibly triple by 1943.

Aluminum reduction in Canada began in 1909 with the establishment of a reduction plant at Shawinigan Falls on the St. Maurice River. It was greatly expanded in 1925 by the construction of a large plant at Arvida on the Saguenay River. Production trends have followed those of the United States (Figure 15), with a rise from 1912 to 1919, followed by a decline and another rise in the late 1920's. Production dropped to a low in 1934 and has increased since that date. Production averaged 12,000 to 15,000 tons annually until recent years. In 1940 the output was 96,000 tons, approximately half that of the United States. The increase since 1940 has not kept pace with that of the United States.

TRADE IN ALUMINUM

The United States and Canada are the only producers of aluminum in the Western Hemisphere. They are also the only important consumers of the metal. Production in the United States is normally a little less than the domestic requirements and there is a small margin of imports over exports. Imports averaged approximately 10,000 tons between 1930 and 1939, and met only about 10 per cent of our total requirements. During the decade imports fluctuated considerably, varying from 12,300 tons in 1930 to 4,000 tons in 1932, rising to 22,000 tons in 1937 and dropping to 8,500 tons in 1938, only to rise again to 14,000 tons in 1939. Imports are largely from Canada, Norway, and Switzerland. These supplied an average annual tonnage of 3,000, 8,000 and 1,600 tons, respectively, during the decade ending in 1939. Imports from Canada increased steadily from 1,500 tons in 1931 to about 4,000 tons in 1939 and rocketed to 15,000 tons in 1940. Imports from Switzerland were small, averaging less than 2,000 tons annually. Those from Norway dropped from 6,000 tons in 1934 to 2,000 tons in 1939.

Exports from the United States during the decade from 1930 to 1939 were approximately two-thirds as great as the imports. During this period the average annual excess of imports over exports was almost 4,000 tons. In view of the fact that the average annual consumption of aluminum during this period was nearly 100,000 tons, the imports were insignificant. Exports have gone to several Western Hemisphere consumers, but about two-thirds of the total has been to consumers in Europe and Asia,

notably the United Kingdom, Germany, Japan, and China. Japan has been the leading foreign purchaser of United States aluminum, but the annual trade averaged less than 2,000 tons and was never more than 5,000 tons.

The Western Hemisphere markets for aluminum outside the United States are small. In normal years a total of a little more than 2,000 tons is exported to Canada, Mexico, Brazil, and Argentina. The largest consumer to the south of us is Brazil, whose requirements prior to 1939 were about 5,000 tons annually. The exports of the United States to Brazil increased from less than 10 tons annually between 1932 and 1938 to 700 tons in 1939 and to more than 2,000 tons in 1940. Canada normally supplies more aluminum to Brazil than does the United States. Exports from the United States to Canada have been largely of semi-manufactured aluminum in the form of plates, sheets, bars, strips, and rods.

Normally, most of Canada's aluminum production is exported. Her domestic requirements are small, and the size of the industry warranted by the favorable location and production factors permits economical production far beyond the domestic needs. Exports increased from 7,800 tons in 1924 to 23,000 tons in 1930, then dropped to 13,000 tons in 1932 and increased to more than 70,000 tons in 1939. The United States, United Kingdom and Japan are normally the leading markets for Canadian aluminum (Figure 16). Two-thirds or more of the exports are sent to the United Kingdom. This flow increased from 825 tons in 1924 to 4,000 tons in 1930, dropped slightly in 1931 and rose steadily thereafter, reaching nearly 39,000 tons in 1939. It has probably become much greater since the outbreak of war. Britain's domestic aluminum industry normally supplies a large portion of her needs, but it is dependent upon imported bauxite. Since European bauxite has not been available in recent years, Britain's industry has declined and Canada, being less severely handicapped by wartime conditions, has supplied a large part of her aluminum requirements. Most of the increased production of Canada since 1934 has gone to the United Kingdom, and less and less to the United States. This is partly because of the increasing requirements in the United Kingdom, and partly because of an increased ability on the part of the United States to supply her own needs.

FUTURE OF THE ALUMINUM INDUSTRY IN THE WESTERN HEMISPHERE

Production Outlook.—Within the past decade there has been a tremendous increase in aluminum production in the Western Hemisphere to meet the very rapidly growing demands with the approach and progress of war. Production in the United States increased 835 per cent between 1934 and 1941, and wartime needs were expected to require that the 1941 production be more than tripled by 1943. The Canadian output increased more than 600 per cent from 1934 to 1940. The 1940 production was more than doubled in 1941 and again by 1943.

Since the wartime requirements for aluminum are much greater than any previous peace-time consumption, radical reductions in production and other adjustments may be expected during the next decade. Consumption during the period of postwar readjustment may be greater than pre-war levels. There is little reason to believe, however, that the 1943 rate of production will continue indefinitely. In fact, reports indicate that a cut-back in production is already in progress. It has been stated that during January, 1944, the Office of

Defense Transportation suggested to the War Production Board that the production in West Coast plants be reduced some four-fifths in order to ease the burden on railroads between the aluminum plants in the southeast and these reduction plants. If carried out this need not have a permanent effect, since peace-time shipping conditions would dictate that such a heavy commodity as alumina be shipped via Panama Canal to these plants. Some of it is shipped this way now, and most of it probably would be if shipping space were available. Indeed, the basis for the original establishment of reduction plants on the West Coast was water transportation from the Gulf Coast alumina producing centers to the available low-cost electricity of the northwest. Reports also indicate that six reduction plants in the eastern United States will soon be partially or completely shut down and total production reduced approximately 14 per cent. Indications point to a reduction of about one-fourth in our total production capacity by the end of 1944.

Production of aluminum in Canada also seems likely to decrease during the next few years. Most of the recent increases have been to meet the war-time needs of Canada, the United Kingdom, and the United States. Exports to the United States have already practically ceased, since our needs are more than completely met by domestic capacity. The huge expansion which resulted from purchases by the United Kingdom soon will not be required, since the industry of that country will doubtless resume its former production rate after bauxite becomes available again. Exports to these and other markets may be expected to decline or be discontinued entirely as the normal conditions within the world aluminum industry return following the war.

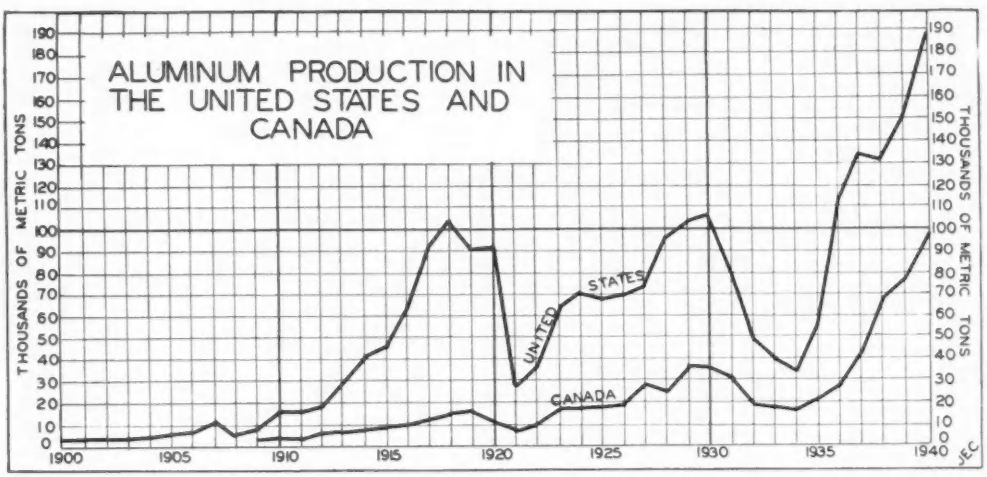

FIGURE 15.—Aluminum production in the United States and Canada, 1900–1940. (Data from Minerals Yearbook.)

South America.—There has been in previous years no production of aluminum in South America. Several of the countries to the south of us, particularly those possessing good bauxite, are interested in developing the industry. Brazil is noteworthy in this respect. Because of the war-time difficulties in importing even small quantities of aluminum from the United States and Canada, the desire to develop her own bauxite resources, and for other reasons,

Brazil is preparing to produce aluminum. A desire to become a commercial producer of aluminum for export is perhaps over optimistic, since the necessary materials for aluminum production are not conveniently located, nevertheless, there is no reason to believe that a small scale industry to meet the growing domestic requirements cannot be economically established. Brazil might also be able to export some aluminum to neighboring South American markets.

Plans have been made and construction has begun on a 10,000-ton alumina plant and a 2,000-ton reduction plant at Sarahenha, near Ouro Preto, Minas Gerais. These will use bauxite from the near-by deposits and power from two hydroelectric plants on the Rio Maynart. Orders for the equipment have been placed in the United States and priority has been obtained, but the shipping shortage has delayed delivery and plans for production have been interrupted, perhaps until after the war. Plans have also been made for development of the Pocos de Caldas bauxite deposits and for the production of aluminum at a plant to be built near Sao Paulo. The shortage of critical materials will probably delay completion of the project until after the war.

Meanwhile, a third aluminum company is being organized for the purpose of installing a plant at Campos, the sugar producing center in the state of Rio de Janeiro. Bauxite is to be supplied from the Itatiaya deposits which are within easy access of Campos and the ports of Rio de Janeiro and Victoria. Plans for production call for 2,000 to 3,000 tons of aluminum annually and also by-products for purifying locally produced sugar. These plants, too, will probably have to await the availability of machinery and probably will not be completed until after the war.

A fourth locality in which aluminum reduction may be established is in the Sao Francisco River valley of eastern Brazil. A series of dams are being constructed for the purpose of developing the agricultural and mineral resources of the area, including bauxite.

There are several waterfalls in Surinam and British Guiana which are capable of furnishing electric power for aluminum reduction, using the near-by bauxite of these colonies. These areas seem likely to continue indefinitely as exporters of bauxite, however, for they lack many of the requisites for aluminum production, and they would have to export practically all of their production and since they can economically sell bauxite in established markets.

Possible Changes in Production Centers.—Some changes in the aluminum producing centers have already occurred and additional changes may be expected in the future. At the time when domestic bauxite resources in Arkansas supplied a major part of the raw materials for aluminum production, a single alumina plant at East St. Louis, Ill., sufficed. With the greater dependence on imported ore, alumina preparation spread to Gulf Coast ports having easy access to South American bauxite. The establishment of aluminum production near Canadian hydroelectric sites led to the establishment of an alumina plant in the same area, also having access by water to foreign ores. With the decline of production of United States bauxite which may be expected in the future, in view of the limited reserves and the recently accelerated rate of production, there may be expected further changes in the centers of alumina and aluminum production. Aluminum production has already spread to the areas of available water power in Canada and northwestern United States, and the alumina plants will

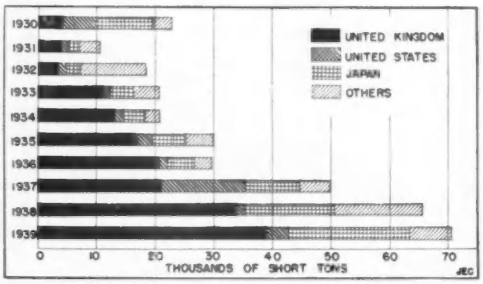

FIGURE 16.—Canadian aluminum exports, 1930–1939. (Data from Minerals Yearbook.)

tend to follow if the transportation factor does not counteract the attraction. Water transportation, plus the large amount of hydroelectric power in these locations, may cause additional shift in the industry.

An additional factor to be considered, in view of our diminishing reserves of bauxite, is the future availability of the ore. The bauxite of Surinam and British Guiana, since they are colonies of European states, may not always be available to the United States and Canada, especially to the United States. Brazil has abundant ore reserves but seems interested in developing an aluminum industry of her own and probably would like to supply the United States with ingot or semi-manufactured aluminum. There are, of course, abundant reserves in Africa and elsewhere outside the Western Hemisphere on which we could draw, and there is little likelihood of a lack of supply. Moreover, the ore of Brazil and of other South American areas will probably be available for some time into the future if not indefinitely.

Low-Grade Bauxite and Non-bauxitic Ores.—In addition to the high-grade bauxite as the normal source of aluminum, there is to be considered the large quantities of lower grade bauxite and several non-bauxitic aluminous materials which may in the future become important sources of metallic aluminum. Already American producers are using lower grade bauxite. In past operations with the Bayer method of producing alumina, approximately one and one-half pounds of alumina have been lost in removing each pound of silica from bauxite. This has limited the silica content of ores to seven per cent. A method of reclaiming this previously lost alumina has been developed and is to be used in the new alumina plant at Hurricane Creek, near Bauxite, Arkansas (Figure 13). If successful, as it apparently is, this will make it practical to use the 9,000,000 tons of United States bauxite reserves which contain from seven to 15 per cent silica and which have formerly been considered uneconomical. This development should double the life-expectancy of the United States buaxite resources. The extra operation required increases somewhat the production cost, but this may be offset by the proximity of the ore reserves to the existing Bayer plants which, with minor modifications, can be adapted to the newer process.

Experimentation in the use of alunite and high-alumina clays as sources of aluminum is progressing and these may supplement or partially replace bauxite as a domestic aluminum ore. Alunite occurs in commercial quantities in Arizona, Nevada, Utah, and Washington, and attempts are being made to use it as a source of aluminum. A pilot plant near Salt Lake City, Utah, with a 30,000-ton annual capacity now produces alumina from alunite (Figure 13). The alumina is used in the Tacoma, Wash., aluminum reduction plant. A by-product derived from alunite is potash, which shares the production costs. It seems rather doubtful, however, if much revenue can be derived from the sales of potash because of the apparently low potash content of the alunite and the difficulty of producing pure

(soda-free) potash. The long range outlook for alunite as a source of alumina is not clear. The proven United States reserves of alunite with an alumina content of 30 per cent or more total only 9,433,000 tons. At the estimated 1942 rate of consumption, if this were our only source of aluminum ore, it would be exhausted in a little more than three years.

During 1944 a plant designed to produce alumina from local clays is expected to be completed at Salem, Oregon. Its initial capacity is to be 50 tons per day. The estimated cost at that capacity is $75 to $80 per ton, as compared with the present price on the west coast of about $60, but the plant is expected to expand and to reduce the production cost. The presence of this possible source of aluminum near the low-cost electric energy of this region is noteworthy. The location would eliminate transportation of bauxite or alumina from the southeast and would result in a saving on transportation which would favor the clay as a raw material. Moreover, the presence of a growing aluminum market on the west coast would favor the location of the complete aluminum production process in that area. Developments may be significant in the future of the aluminum industry of the United States.

WATER SUPPLY GEOGRAPHY OF THE BASIN OF THE RED RIVER OF THE NORTH IN THE UNITED STATES

J. R. Schwendeman

The Organized Water Supply Systems of the Cities and Towns

In the previous installment of this series of articles was presented and discussed the importance of the Red River Basin as an agricultural area, its physical geography, and the close dependence of the agricultural economy upon the ground water supply in particular.

The present article shows how water supply affects the distribution and development of the cities and towns.

Distribution of Cities and Incorporated Towns and Villages

Of the 513,182 people in the Basin 402,850 or about 80 per cent live in incorporations ranging in size from 102 in Leal, North Dakota to 32,580 in Fargo, North Dakota. On the farms and unincorporated villages live 111,332 people or about 20 per cent of the population. The incorporated places number 223 with only 12 reaching urban rank of 2,500 or over. Of the rest, 33 have a population of 1,000 to 2,500; 32 from 500 to 1,000; and 146 are small villages of under 500 people. These localities are scattered uniformly over the basin (Figures 1 and 2).

Water Supply and Distribution of Incorporated Places

Just how large a population concentration can be provided with water within the Red River Basin cannot be definitely stated at the present writing. The Fargo–Moorhead urban center has 42,071 people. In 1936 at the height of the dry cycle, Fargo, North Dakota had reached the point of exhausting her visible water supply. Fortunately Moorhead, Minnesota had developed an artesian system fully adequate for her own needs leaving Fargo the Red River for its water supply. At this time the Red River supply was inadequate for both towns but sufficient for one. To what extent the artesian supply would have sufficed for Fargo–Moorhead can not be stated. At this writing a combined Federal-Local investigation is under way to answer this vital question for the Fargo–Moorhead community.

Because of the small size of incorporated places and their wide and uniform distribution over the Basin few other critical water shortages have developed. Breckenridge, Minnesota in the winter of 1936 was cut off from water because the Red River froze to its bottom. Ground water, through wells, is the only supply of most of the incorporations with the remainder having wells as reserve or supplementary supply.

Water Supply and the Development of Cities and Villages

River water supply would prove extremely limiting and hazardous for the Basin as a whole. Rivers are few, small, and sluggish with little or no water

during droughts and the long cold winter. Old timers relate that General Sibley had to dig a well in the bottom of the Red River in order to supply his troops during the Sioux War of 1862–63. Wells have been responsible for the uniform development of the basin in supplying water wherever the building of a town or city seemed desirable and economical.

PREVIOUS REPORTS ON ORGANIZED SYSTEMS

The National Resources Committee report of August 1937, Regional Planning, Part V Red River of the North, covers stream discharge and some of the factors affecting water supply in the basin. The problem of water supply for some of the larger systems such as Fergus Falls, Minnesota, Fargo, North Dakota, and Grand Forks, North Dakota is well covered, particularly, in relation to stabilizing the supply. Conservation of surface water supply in the basin is also fully treated. This Regional Planning Report does not treat the consumption of water in the basin.

A survey of water consumption for the North Dakota side of the basin was

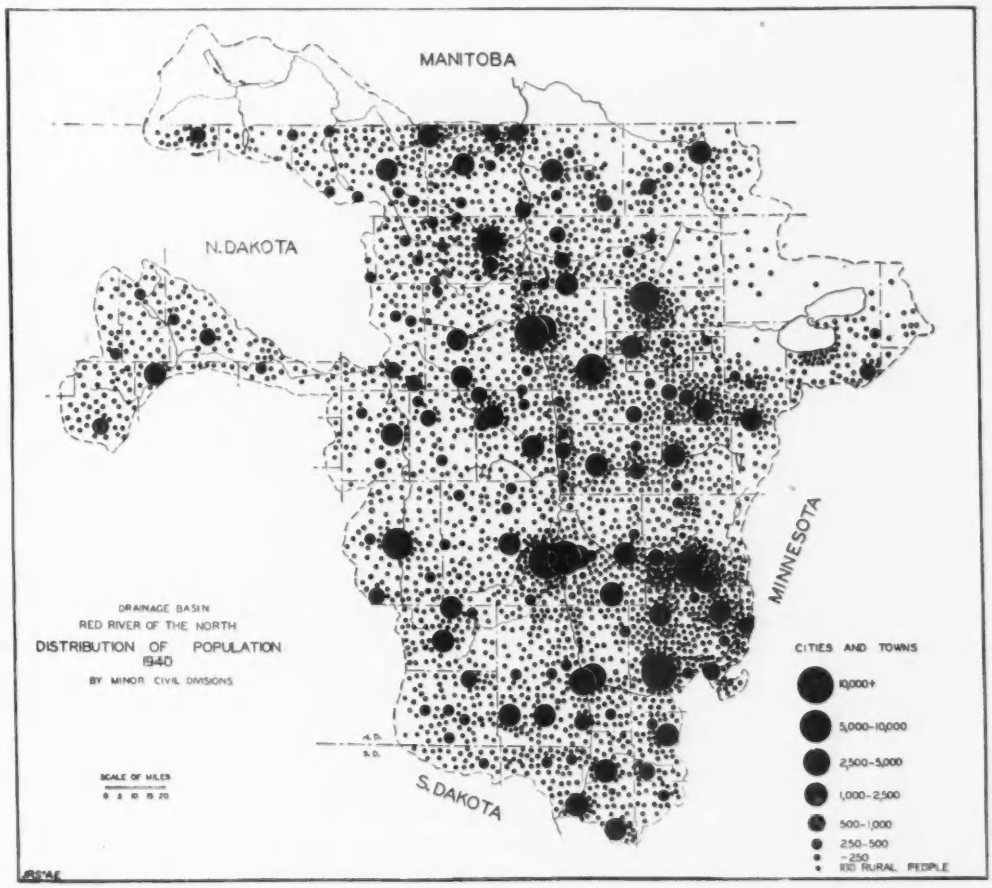

FIGURE 1.—The 1940 population distribution of the Basin of the Red River of the North by minor civil divisions and municipalities from the Sixteenth United States Census. The population is uniformly distributed over the basin, the only exception being the two urban centers of Fargo–Moorhead and Grand Forks and East Grand Forks. Fargo and Grand Forks are in North Dakota and Moorhead and East Grand Forks in Minnesota.

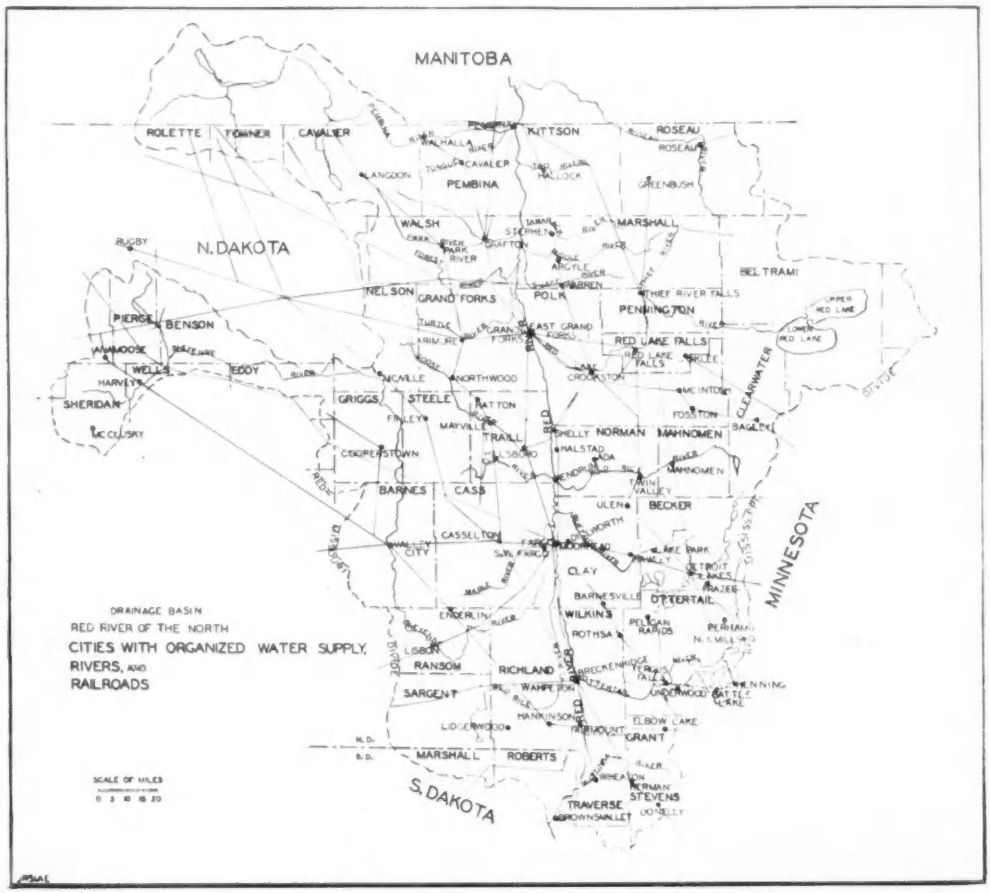

FIGURE 2.—The railway pattern in the Basin of the Red River. This map also shows the cities with organized systems of water supply.

made in 1935 by the North Dakota State Planning Board entitled—*North Dakota State Planning Board Report of Water Consumption and Supply for North Dakota Cities*. This report gives the annual consumption of water in gallons of organized systems which returned the questionnaire they sent to the Postmasters of each town for information. It also gives the source of water supply and treatment of sewage. This report has been very helpful in checking the results of the present survey.

A 1927 revision of an earlier survey of North Dakota systems was printed in Water Supply Paper 598, Geology and Ground Water Resources of North Dakota, (1929). This survey is reproduced here as Table XV for such of the cities as are represented in the present survey of the Red River basin. This survey is particularly useful geographically, in that it shows the prevalence of the water tower or standpipe to provide water pressure in this basin of prevailing level and flat lands.

The present survey was conducted in the fall of 1940 and is largely a questionnaire survey. Questionnaires were sent to all urban centers and to all other incorporated towns of 300 population or above. (Tables I to IV inclusive show distribution of population and

TABLE I

WATER CONSUMPTION DATA IN ORGANIZED SYSTEMS FOR THE RED RIVER BASIN
CLASSIFIED ACCORDING TO SIZE OF POPULATION

City and State	*Population 1940*	*Gallons Consumed 1939*	*Gals. per Day per Person*	*Gals. per Day per Meter*	*Source of Supply*	*Well Depth in Feet*	*Sewage Treatment*
			Urban Population—Cities 2,500 and Over				
Breckenridge Minnesota	2,745	50,297,857	50	197	River	.....	None at present
Crookston Minnesota	7,161	218,578,000	83	393	Red Lake River	.....	Sewage to river
Detroit Lakes Minnesota	5,015	170,537,095	93	748	Lake	.....	Imhoff tank
East Grand Forks Minnesota	3,511	73,300,000	57	683	Red Lake River	.....	River disposal
Fergus Falls Minnesota	10,848	339,030,000	85	511	Otter Tail River	.....	Partial
Fargo North Dakota	32,580	1,193,774,000	100	563	Red River Reserve Wells	.....	Rock filter
Grand Forks North Dakota	20,228	699,776,000	83	398	Red Lake River	.....	Primary
Grafton North Dakota	4,070	72,169,000	48	501	Artesian well	320	Filter
Moorhead Minnesota	9,491	249,897,169	72	377	Six deep wells	240–273	Activated sludge
Thief River Falls Minnesota	6,019	133,338,000	60	348	Red Lake River	.....	Pre-clar. trick filter
Valley City North Dakota	5,917	197,511,000	91	481	Three wells	50	Activated sludge
Wahpeton North Dakota	3,747	94,573,400	70	325	Red River Two artesian wells	420 265	Sludge digestion
Totals	[a]111,332	3,402,781,521	..	...	1 river and well 7 rivers 3 wells 1 lake	.....	9 treatments
Average	.....	.....	74	460	.....	.....	.....
Percentage			[a]50.7% of incorporated population [a]21.6% of total population				

water supply and consumption for the cities replying to questionnaires.)

There are twelve cities in the Red River Basin with an urban rating of 2,500 population or above. These cities contain 111,332 people or 50.7 per cent of the incorporated population. All of these responded to the questionnaire.

Thirty-three cities have populations of 1,000 or over with 46,726 people or 21.3 per cent of the incorporated population. Of these, 27 cities or about 82 per cent replied to the questionnaire. Some data for three of the cities not responding was obtained from the North Dakota State Planning Board report, making practically 100 per cent coverage for cities in this class. All of these cities of 1,000 population or over have organized water supply systems of some kind.

About the same number of cities, 32—not all organized—are in the 500 to 1,000 population class containing 21,934 or 10 per cent of the incorporated population. Of this group, 27 cities or 84.3 per cent replied to the questionnaire. About 20 towns of this size have some kind of water supply organization.

Sixty towns of the basin are in the 300–500 population class with 22,300 population or 10.1 per cent of the incorporated population. Forty-seven cities or 78.3 per cent replied to the questionnaire. Six of these appeared to have some type of organized system. The remainder reported unorganized

TABLE II—WATER CONSUMPTION DATA IN ORGANIZED SYSTEMS FOR THE RED RIVER BASIN CLASSIFIED ACCORDING TO SIZE OF POPULATION

City and State	*Population 1940*	*Gallons Consumed 1939*	*Gals. per Day per Person*	*Gals. per Day per Meter*	*Source of Supply*	*Well Depth in Feet*	*Sewage Treatment*
			Urban Population—Cities 1,000 to 2,500				
Ada Minnesota	1,938	9,513,300	13	56	Three wells	255	Imhoff tank
Bagley Minnesota	1,241	14,240,000	31	300	Two wells	140–175	Mechanical under construction
Barnesville Minnesota	1,450	No record			Three wells	80 150 180	Activated sludge
Browns Valley Minnesota	1,075	6,000,000	15	126	Three Wells One spring	400 400 25	Septic tank
Casselton** North Dakota	1,358	8,199,605	17	177	Well	316	Septic tank
Cavalier** North Dakota	1,105	4,420,000	4	...	Flowing well	.....	None
Cooperstown North Dakota	1,077	5,656,445	14	103	Two wells	44 56	Septic tank
Dilworth Minnesota	1,068	No record			Wells	154 157	Moorhead system
Elbow Lake Minnesota	1,150	25,400,000	60	174	Well	222	Septic tank
Enderlin** North Dakota	1,593	26,425,000	29	...	Artesian well	.....	No record
Fosston Minnesota	1,271	No record	(Flat rate)		.....	.....	.....
Frazee Minnesota	1,167	No report					
Hallock Minnesota	1,353	25,000,000	50	...	Two rivers	.....	No report
Hankinson North Dakota	1,420	No report	(New system)		Two deep wells	156	Tank
Harvey North Dakota	1,851	45,120,000	67	...	Wells	.....	No record
Hawley Minnesota	1,122	No report			Well	.....	.....
Hillsboro North Dakota	1,338	No report			Well	92	No public
Langdon** North Dakota	1,546	9,125,000	17	...	Well	.....	No treatment
Larimore North Dakota	1,222	15,000,000	34	213	Two wells	42	Imhoff tank
Lidgerwood North Dakota	1,042	1,825,000	5	20	Six artesian wells One other	625 65	No report
Lisbon North Dakota	1,997	13,614,500	19	...	Flowing well	.....	No report
Mahnomen Minnesota	1,429	No record	(Flat rate)		Artesian well	.....	River disposal
Mayville North Dakota	1,351	13,000,000	26	138	Goose River well supplement	357	Imhoff tank
Northwood North Dakota	1,063	No report					
Park River North Dakota	1,408	22,344,690	43	215	Artesian well	480	Septic tank
Pelican Rapids Minnesota	1,560	7,000,000	12	85	Deep well	115	Simplex aerator
Perham Minnesota	1,534	No report					
Red Lake Falls Minnesota	1,530	19,060,300	34	189	Well	175	Sanitary disposal under way
Roseau Minnesota	1,775	16,965,000	26	179	Two wells	90 100	Disposal plant
Rugby North Dakota	2,215	18,980,000*	23*	693*	Well	.....	.....
Walhalla North Dakota	1,138	1,000,000	..	...	Two wells	16 24	River disposal
Warren Minnesota	1,639	32,000,000	53	146	Three wells	130	Septic tank
Wheaton Minnesota	1,700	19,681,650	33	116	One well	149	No treatment
Totals	[a]46,726	340,590,490	..	...	1 river 26 wells 1 well and spring 1 river and well	.....	14 treatments
Average	.....	.....	29	149	.....	179	.....
Percentage	[a]21.3% of incorporated population				[a]9.1% of total population		

*Old data—not computed in total. **From North Dakota State Planning Board.

water supply with the villagers providing their individual needs in various ways.

There are 86 incorporated villages under 300 population listed in the basin with a total population of 16,885 or 7.9 per cent of the total incorporated population. Some scattered reports have been obtained for these. None of these villages reported organized systems and it is quite certain that none of these have organized water supply systems, since, so few of the larger group from 300–500 have any kind of organization. There may be one or two exceptions. All of the reports for these villages showing unorganized systems are considered later.

Tables I to XIII inclusive summarize the most important items ascertained

TABLE III

WATER CONSUMPTION DATA IN ORGANIZED SYSTEMS FOR THE RED RIVER BASIN CLASSIFIED ACCORDING TO SIZE OF POPULATION

City and State	*Population 1940*	*Gallons Consumed 1939*	*Gals. per Day per Person*	*Gals. per Day per Meter*	*Source of Supply*	*Well Depth in Feet*	*Sewage Treatment*
			Urban Population—Cities 500 to 1,000				
Argyle Minnesota	857			No report			
Battle Lake Minnesota	623	6,325,000	28	137	Well	75	Private cess pools
Fairmont North Dakota	705	21,900,000	85	...	Three wells	120–130	No report
Finley North Dakota	677	No record	22 (Current)	357 (Current)	Well	50	Imhoff tank
Greenbush Minnesota	556	No record	(No master meter)		Well	185	None
Halstad Minnesota	570	No separate meter (flat rate)			Two wells	290	Sewer to Red Lake
Hatton North Dakota	933	1,919,150	6	66	Well	245	Private septic tanks
Henning Minnesota	948	No record	(Flat rate)		Well	.....	No report
Herman Minnesota	703	No record	..	...	Well	150	No report
Lake Park Minnesota	654			No report			
McClusky North Dakota	924	4,745,000	14	...	Well	.....	None
McIntosh Minnesota	903	500,000*	1.5*	...	Well	.....	No report
McVille North Dakota	548	3,650,000	19	...	Well	.....	None
New York Mills Minnesota	771	1,500,000	53	328	Reservoir	.....	Municipal plant-treated
Pembina North Dakota	703	No record	(Newly organized in 1940)		.....	.....	Sewer to Red River
S. W. Fargo North Dakota	707	3,617,000	14	115	Well	132	Private cess pools
Stephen Minnesota	673	No record	(Newly organized)		Stream	.....	Disposal plant
Twin Valley Minnesota	844	3,250,000	11	45	Two tubular wells One unused sandy well	250 150	Cess pool
Ulen Minnesota	562	No meters in system (flat rate)			Well	160	No report
Totals	[a]13,861	46,906,150	..	...	14 wells 1 stream 1 reservoir	.....	4 treatments
Average	.....	.....	28	174	.....	161	.....
Percentage		[a]6.3% of incorporated population [a]2.6% of total population					

*Data not verified and hence not used in computation.

from the questionnaire pertaining to the size, annual consumption, per capita consumption, per meter consumption of water—both the latter on a daily basis—the source of supply, length of record, and type of sewage disposal of the city.

most of them quite small, it is remarkable that the modern conveniences of organized water supply are so extensively available. This situation is to a large extent due to the readiness with which an adequate supply of well water can be obtained requiring no treatment

SURVEY QUESTIONNAIRE

ORGANIZED URBAN WATER SUPPLY SURVEY—RED RIVER BASIN

By—Geography Department

State Teachers College, Moorhead, Minnesota

1. Name of city ..... 1940 population .....
2. Source of water supply? Stream ..... Artesian well .....
   Lake ..... Spring ..... Reservoir ..... Other .....
3. Number of services in system? ..... Are all services metered? .....
4. What is the annual water consumption in gallons for these years?
   1939 ..... 1935 ..... 1930 .....
   1925 ..... 1920 ..... 1915 .....
   1910 ..... 1905 ..... 1900 .....
   1895 .....
5. What is the monthly consumption of water in the year 1939?
   Jan. ..... Feb. ..... March .....
   Apr. ..... May ..... June .....
   July ..... Aug. ..... Sept. .....
   Oct. ..... Nov. ..... Dec. .....
6. What hour of the day is the peak load usually reached? .....
7. What is the maximum day's consumption ..... gallons? In what season does it occur? .....
8. If the city supplementary supply is from wells, what is the number and approximate depth of the wells? ..... Do they reach bedrock? ..... (If possible, please give a generalized log of one of the newer wells on the back of this sheet.)
9. Is your city water supply adequate for all present purposes? .....
10. Does it allow for future growth of the city? .....
11. Is your water supply naturally pure? ..... If not, is it chemically treated? .....
12. What type of sewage disposal is used? .....

Considering the survey of the organized systems as a whole, it is very important to note that 79 per cent of the incorporated population of the Red River basin has access to an organized water supply system. Considering that this 79 per cent is widely distributed over the basin (Figures 1 and 2), and consists of 129 cities, towns and villages, or filtration before using. A second item of striking importance is that 78 per cent of the organized systems depend wholly on well water and several of the remaining 22 per cent in part (Tables I to XIII). While it is true that the larger cities depend on river water, nevertheless, the large number of systems depending on well water

point to the fact that an exhaustion of the well water resource would have most serious consequences in the basin.

Another important item to note in water uses by the organized systems is the low per capita consumption per day—about 30 gallons per person—outside of the larger systems (Tables II to IV). This is probably due in part to the fact that in these small cities and towns there is little or no industrial or public consumption of water.

As an illustration of the extent to which the industrial and public consumption increases the per capita per day index of consumption, this distribution of water use is allocated in the city of St. Paul, Minnesota in their 1939 report on water consumption. In St. Paul the per capita consumption is 75 gallons per day. Commercial consumption uses 42 per cent of this or about 32 gallons per person per day. This leaves 45 gallons per person per day for domestic consumption. White and Renner in their Geography, *An Introduction to Human Ecology*, page 535 give the average per capita domestic consumption for all types of communities at 18 to 20 gallons per day. This latter figure is below the 30 gallons per day average per person for the Red River Basin towns of around 1,000 population and under. Another explanation for the basin's low average daily consumption lies in the fact that many of the small Red River systems are new, with many of the homes still using private well and cistern supplies either wholly or in part.

Again, the domestic consumption per meter in the St. Paul, Minnesota system is 190 gallons per day. The 100 gallons per meter per day for the Red River basin small towns compares more favorably with St. Paul's consumption in this respect.

The Red River Basin urban systems compare favorably with the St. Paul system at 74 gallons per person per day and 460 gallons per meter per day, suggesting that water use in the Red River Basin cities compares favorably with the use of water in other cities. Detroit Lakes, Minnesota, the only system drawing its supply from a lake,

TABLE IV

WATER CONSUMPTION IN ORGANIZED SYSTEMS FOR THE RED RIVER BASIN CLASSIFIED ACCORDING TO SIZE OF POPULATION

City and State	*Population 1940*	*Gallons Consumed 1939*	*Gals. per Day per Person*	*Gals. per Day per Meter*	*Source of Supply*	*Well Depth in Feet*	*Sewage Treatment*
Urban Population—Cities 300 to 500							
Anamoose, North Dakota	495	2,200,000	13	75	Two wells	150	Cess pool
Donnelly, Minnesota	370	No record			Well	150	None
Hendrum, Minnesota	341	No record	(Flat rate)		Well	285	Sewer to river
Oklee, Minnesota	414	No record			Well	278	No report
Rothsay, Minnesota	415	No record	(New system)		Well	167	Cess pool
Shelly, Minnesota	344	No record	(Flat rate)		Well	.....	None
Underwood, Minnesota	353	No record	(New system)		Well	140	Individual septic tanks
Totals	[a]2,732	2,200,000	...	...	7 wells	.....	2 treatments
Average	.....	.....	13	75	.....	195	.....
Percentage	[a].5% of total population						

[a] 1.2% of incorporated population

TABLE V

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	Population 1940	Gallons Consumed 1939	Gals. per Day per Person	No. of Meters	Gals. per Day per Meter	Source of Supply	Well Depth in Feet	Sewage Disposal
North Dakota—Goose Pembina Sub-basin								
Cavalier*	1,105	4,420,000	4	No report		Flowing well	.....	None
Fargo	32,580	1,193,774,000	100	5,800	563	Red River well supplement	.....	Rock filter
Grafton	4,070	72,169,000	48	395	501	Artesian well	320	Filter
Grand Forks	20,228	609,776,000	83	4,200	398	Red Lake River	.....	Primary
Hatton	933	1,919,150	6	80	66	Well	245	No public
Hillsboro	1,338	Data not recorded		297	No data	Well	92	No public
Langdon*	1,546	9,125,000	17	No report		Well	.....	No report
Larimore	1,222	15,000,000	34	197	213	Two wells	42	Imhoff tank
Mayville	1,351	13,000,000	26	258	138	Goose River well supplement	357	Imhoff tank
Park River*	1,408	22,344,690	43	285	215	Artesian wells Surface wells	480 45	Septic tank
Pembina	703	System organized in 1940 (no data available)				Red River	.....	Sewer to Red River
Walhalla	1,138	1,000,000	Not all metered	112	Not all metered	Two wells	20–40	Sewer to river
Totals	[a]76,622	1,942,527,840	...	Number using river ..... 4 Number using wells ..... 10 Number of wells used 14			.....	6 treatments
Average	.....	.....	41	.....	313	.....	181	.....
Percentage	[a]30.8% of incorporated population of Red River Basin [a]13.1% of total population of Red River Basin							

*From North Dakota State Planning Board.

has the highest daily consumption per meter of 748 gallons as compared with the average of 460 for the cities of the basin and 563 gallons for Fargo, North Dakota, the next highest. Detroit Lakes has also a per person consumption of 93 gallons per day which is only second to Fargo, the largest city in the basin. Detroit Lakes is located immediately on the shores of a large lake.

Total annual water consumption for the basin by organized systems is not large (3,792,478,161 gallons). Compared with such consumption as the Boston Metropolitan supply system (46,924,035,000 gallons per year) it is small indeed (Table XIV).

THE ORGANIZED SYSTEMS DEPENDING UPON WELL WATER

Wells constitute the source of supply for 50 out of the 64 organized systems reporting source of water supply. All but one of the municipalities under 2,500 population have one or more wells as a source of supply. Even three of the 12 cities of urban size depend on wells and two others use wells as supplementary or reserve. On the basis of population of the organized systems the wells supply 77,574 people or 44 per cent.

Moorhead, Minnesota is the largest of the organized systems depending wholly on wells and ranks fourth in size in the basin with a 1940 population of 9,491 people. Several cities such as Moorhead, Minnesota and Valley City, North Dakota use wells for city supply, despite the fact, that they are located on the banks of rivers—the Red and Sheyenne respectively.

Having a youthful drainage system with few widely dispersed streams, low gradient, and comparatively low discharge of water, it is fortunate that the basin is provided with such widespread water bearing strata of considerable storage capacity—largely free from undesirable salts, impeding sediments,

mostly near the surface and easily reached by well drilling appliances.

Water Supply Paper 489 shows that the basin has rock strata of four periods which are water-bearing. The glacial drift of the quaternary covers the entire basin with several hundred feet of loose material enclosing several highly desirable water horizons.

Of the wells reported by the organized systems, all but seven do not reach bed rock and derive their supply from the acquifers of the quaternary drift. According to the water consumption reported by the organized systems, 828,453,309 gallons or nearly 22 per cent of the water is furnished by the Quaternary beds making it a most significant ground water supply.

Figure 3 from Water Supply Paper 598, page 49, (After Upham) shows the nature of the occurrence of these quaternary deposits in the basin and valley of the Red River and their relation to artesian water in the basin. The unconsolidated quaternary material shown in this diagram by Mr. Upham is varying in thickness. A well log shown in the Casselton-Fargo Folio, shows its thickness at 370 feet for both lacustrine and till. The Wisconsin till which composes the bulk of the drift in the basin is placed by Simpson at from 30 to 60 feet deep but at places as much as 500 feet in thickness. The average depth of the wells reported by organized systems which do not reach bed rock vary from 150 to 200 feet.

The difference of level of about 400 feet from the morainic uplands on either side of the Red River to the valley bottom provides considerable head and sufficient pressure for many artesian wells.

Speaking of this artesian phase Simpson says (Water Supply Paper 598, page 39) "The waters of the sandy layers of the drift are in many places under artesian pressure, particularly in the Red River Valley, where the head is derived from the uplap of these water bearing layers over the Pembina escarpment to the west. The till itself is relatively impervious and forms the retaining beds."

Simpson says further respecting the water-bearing capacity of the quaternary deposits, "The water-bearing beds of the quaternary system are numerous, and their positions are extremely variable. Nevertheless, many localities have what the drillers recognize as the 'first water bed' and the 'second water bed' and in some places even the 'third water bed' above the bed rock. These water beds are generally sand or gravelly layers of the drift, but they vary greatily wth locality and in places are absent. The quaternary water-bearing beds most frequently recognized and reported are the sand and silt of the ancient Lake Agassiz and other glacial lakes, the Wisconsin till and other

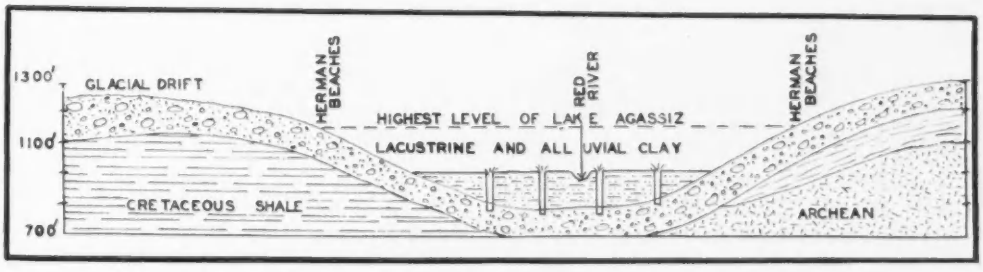

FIGURE 3.—Ideal section of the Red River Valley artesian Basin (after Upham).

morainal deposits, the alluvial outwash of the Wisconsin age, the till and gravel of the pre-Wisconsin age, and the residual soil."

Logs of recent wells reported by organized systems are revealing as to the relation of water supply to the quaternary deposits:

Ada, Minnesota

ADA

Log of 12 inch well drilled August 1940

Soft clay	to depth	78 ft.
Hard blue clay	to depth	78 to 82 ft.
Hard pan clay	to depth	82 to 141 ft.
Fine dirty sand	to depth	141 to 169 ft.
Hard pan	to depth	169 to 175 ft.
Hard pan and dirty sand	to depth	175 to 212 ft.
Dirty sand and gravel	to depth	212 to 216 ft.
Gray sand and gravel	to depth	216 to 228 ft.
Fine sand	to depth	228 to 237 ft.
Coarse gravel and sand	to depth	237 to 260 ft.
Fine sand	to depth	260 to 262 ft.

The city of Ada reports its supply from three artesian wells such as shown by this log with 9,513,300 gallons annual consumption and a peak load of 200,000 gallons for a day occurring in August.

Elbow Lake, Minnesota gives this log for one of their newer wells:

ELBOW LAKE

Sandy soil	to depth	0 to 2 ft.
Clay	to depth	2 to 72 ft.
Fine sand yellow clay	to depth	72 to 90 ft.
Quicksand	at	90 ft.
Coarse sand gravel and blue clay	to depth	97 to 105 ft.
Sand in blue clay	to depth	105 to 159 ft.
Coarse sand (water)	to depth	159 to 165 ft.
Fine sand in blue clay	to depth	165 to 182 ft.
Quicksand	to depth	183 to 186 ft.
Fine sand	to depth	186 to 193 ft.
Coarse sand and a little fine sand	to depth	193 to 200 ft.
Sand fine to coarse	to depth	200 to 222 ft.
Blue clay below		222 ft.

Elbow Lake reports that this well is artesian, that their annual water consumption is 1,800,000 gallons and a maximum summer day consumption is 60,000 gallons.

Warren, Minnesota reports a 16 inch well drilled in the summer of 1940. (This well supplements two wells with 100 gallons per minute capacity.)

WARREN

Soft clay and hard pan (equally divided—soft clay first)	to depth	0 to 130 ft.
Water horizon in-material as follows	to depth	130 to 159½ ft.
Coarse gravel	to depth	130 to 132½ ft.
Quicksand and gravel (2 ft. each)	to depth	132½ to 136½ ft.
Quicksand	to depth	136½ to 159½ ft.
Hardpan follows		

Warren reports 32,000,000 gallons annual consumption with a July day maximum of 110,000 gallons.

The new well at Fargo, North Dakota is 200 feet deep showing 90 feet of silt and clay, 60 feet of till, boulders, and sand, and 50 feet of gravel in descending

TABLE VI

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	Population 1940	Gallons Consumed 1939	Gals. per Day per Person	No. of Meters	Gals. per Day per Meter	Source of Supply	Well Depth in Feet	Sewage Treatment
North Dakota—Sheyenne River Sub-basin								
Anamoose	478	2,200,000	13	80	75	Two wells	150	Cess pool
Casselton	1,358	8,199,605	17	127	177	Artesian well	316	Septic tank
Cooperstown	1,077	5,656,445	14	150	103	Two wells	44–56	Septic tank
Enderlin*	1,593	26,425,000	29	No record		Artesian well	.....	No record
Finley	677	.....	22 (Current)	42	357 (Current)	Well	50	Imhoff tank
Harvey*	1,851	45,120,000	67	No record		Wells	.....	No record
Lisbon*	1,997	13,614,500	19	No record		Flowing well	.....	No record
McVille	548	3,650,000	19	No record		Well	.....	No system
McClusky	924	4,745,000	14	No record		Well	.....	No system
Rugby[1]	2,215	18,980,000	23**	75**	693**	Well	.....	No record
S. W. Fargo	707	3,617,000	14	86	115	Artesian well	132	No public
Valley City	5,917	197,511,000	91	1,125	481	Three wells	50	Activated sludge
Totals	[a]19,996	310,738,550	Number using wells....13 Number of wells used...17			.....	.....	6 treatments
Average	.....	.....	28	.....	201	.....	114	.....
Percentage			[a]9.1% of incorporated population [a]3.8% of total population					

[1]Taken from Water Supply Bulletin 598.
*From North Dakota Planning Board.
**Old data—not computed in totals.

order with granite following the gravel.

Harvey, North Dakota does not give a detailed log but makes the following report: "The water supply seems inexhaustible in Harvey. The people are allowed 5,000 gallons for $4.00 for every three months during the three summer months. However, they are allowed 10,000 additional gallons for the same price to encourage the upkeep of lawns, etc. There are large engines to pump the water up from a very deep well, then it is filtered through a large vat through layers of different types of rock. The surveyors who located the water marked it as coming from an ancient lake bed. The water is pumped up through layers of sand and gravel. They had quite a time locating water for Harvey, but finally after sinking a well one mile south of town they were successful."

Cooperstown, North Dakota reports a dug well as follows: "The new well is a dug well 44 feet deep and 20 feet in diameter, concrete cubing full depth, concrete top. The pump used on this well is a Pomona Turbine three horse power electric motor. The first 21 feet formation is top soil and clay, the next 23 feet is what they call water sand, on the bottom is a shale formation." Cooperstown reports 5,656,445 gallons annual consumption with a 20,000 maximum day occurring in summer.

The report from Hatton, North Dakota gives something of the relation

FIGURE 4.—Approximate temperature of water from non-thermal wells at depth of 30 to 60 feet (After Nathan C. Grover).

of well equipment to this unconsolidated material: "A 16 inch hole drilled to a depth of 185 feet, and a 12 inch Armco iron casing is installed and cemented in at the bottom at this point. A 12 inch hole was then drilled to a depth of 245 feet 6 inches following which the 10 feet of sand from 232 feet to 242 feet was under-reamed to a diameter of eight feet. Then the screen and inner casing was installed, consisting of 50 feet of eight inch Armco iron casing, seven feet of eight inch screen and then five feet of six inch screen and three feet of blank six inch pipe at the bottom installed with concrete plug. Gravel was then placed between the screen and the under-reamed portion of the hole. The well was just drilled in 1938 so 1939 was the first year we used it." Hatton reports 80 meters using 1,919,150 gallons annually. They do not report their maximum day's consumption. The well is reported as artesian, and at 245 feet in depth.

As to quality, Mr. Simpson summarizes the quality of water from the drift on page 30 of his Water Supply Paper 598, "In general, waters from the drift are suitable for all ordinary purposes although those that have been concentrated contain so much dissolved mineral matter that they can not be used."

One *very important* phase of the questionnaire were the answers to the question on quality. To the Question: "Is your water supply naturally pure?" every organized system with a well supply answered, "Yes," and added that no chemical treatment was given whereas every system with a river supply answered, "No" and gave chlorine or ammonia treatment as part of their purification process.

In the western part of the Red River basin the Dakota Sandstone is the commonest source of well water beneath the drift and alluvium. Of it Mr. Simpson says, "The Dakota sandstone is the best water-bearer in the bed rock in North Dakota and is in fact one of the best water bearers in the bed rock in the world because of its wide extent, its high economic value, and particularly because of the reputation of its artesian wells for high head and strong pressure." He adds further as to quality, on the same page, "Many of these waters are too highly mineralized for satisfactory domestic supplies. Their main use is for livestock and protection from fire. A few of the towns, however,

TABLE VII

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	*Population 1940*	*Gallons Consumed 1939*	*Gals. per Day per Person*	*No. of Meters*	*Gals. per Day per Meter*	*Source of Supply*	*Well Depth in Feet*	*Sewage Treatment*
				North Dakota—Wild Rice Sub-basin				
Hankinson	1,420	No record		200		Two wells	156	Tank
Lidgerwood	1,042	1,825,000	5	250	20	Six artesian wells One other well	625 65	.....
Wahpeton	3,747	94,573,400	70	800	325	Two wells Red River	420–265	Sludge digestion
Totals	[a]6,209	96,398,400	Number using wells .... 3 Number wells used .... 11 Number using river 1			.....	.....	2 treatments
Average	.....	.....	37	...	172.5	.....	306	.....
Percentage	[a]2.8% of incorporated population [a]1.2% of total population							

depend entirely on these waters for their supply."

Mr. Simpson's comment as to quality and city use of the Dakota sandstone artesian water is borne out by the fact that only two of the organized systems of North Dakota report deep artesian wells reaching bed rock—Wahpeton at 420 feet, Dakota Sandstone, and Grafton 320 feet, rock formation not specified. Both of these cities report this water as naturally pure, but Wahpeton reports a sandbed well at 265 feet. The Dakota Sandstone as a basin water supply is widely used by farmers for livestock.

In addition to its other high qualities the coolness or low temperature of the Red River Basin well water deserves particular comment as a geographic phase. It is not only highly pleasing and refreshing to drink during the hot summer months, but it is also widely used for rural refrigeration. Figure 4, which represents a map reproduced from Water Supply Paper 520 is highly expressive on this point of the basin's low well water temperature. The Red River basin's well water shows to be from five to ten degrees lower than well water over practically all of the United States for wells of from 30 to 60 feet in depth. One unfortunate result of this low temperature, however, is the higher cost of heating the water for laundrying and bathing, and for electric heating equipment. The double heating unit in electric heaters is advised and is more costly.

From this discussion of the use of well water by organized systems it is apparent that its use is widespread in the basin, that it is important in the economy of the water supply of the organized systems and that there is little or no alternative supply to replace it.

Regardless of the widespread dependency on well water by organized systems, the river supply is extremely important in supplying several of the largest cities of the basin. It is yet doubtful if enough well water could be concentrated at any one point to economically supplant the river supply. According to reports shown in Tables I to IV, 11 cities use river water with a total population of 90,216 or 51 per cent of the organized systems' total population. It is questionable whether enough well water could be concentrated in the larger urban centers by piping or other means, in quantity or cheaply enough for practical purposes. Fargo has repeatedly attempted to find enough local well water for her supply but has, so far, only succeeded in obtaining a reserve supply by no means adequate for replacement of the river source.

As it is, the Red River is taxed to capacity, to meet the needs of Fargo, particularly during the late dry cycle

TABLE VIII

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	*Population 1940*	*Gallons Consumed 1939*	*Gals. per Day per Person*	*No. of Meters*	*Gals. per Day per Meter*	*Source of Supply*	*Well Depth in Feet*	*Sewage Disposal*
				North Dakota—Bois des Sioux				
Fairmont	705	21,900,000	85	No report		Two wells	120–130	No report
Totals	[a]705	21,900,000	..	...	...	Two wells	.....	None
Average	.....	.....	85	...	...	.....	125	.....
Percentage								

[a].3% of incorporated population
[a].1% of total population

years and the river does not assure an adequate reserve for even the present, not to mention the future.

The cities and towns reporting dependence on river water are on the Red River or east of it with the exception of Mayville, North Dakota which uses well water in part. These places are Breckenridge, Crookston, East Grand Forks, Fergus Falls, Thief River Falls, Hallock, and Stephen in Minnesota and Fargo, Grand Forks, Wahpeton, and Mayville in North Dakota.

THE WATER SUPPLY AND CONSUMPTION OF THE CITY OF FARGO, NORTH DAKOTA

The city of Fargo is today the largest user of water in the valley with an annual consumption which first reached the billion gallon mark in 1929 (Figure 5 and Table XVI) and has remained near or above that mark since, with 1936 being the peak year of approximately one and one-fourth billion gallons. The Fargo water system supplies 32,580 people and has 5,800 meters. The per capita consumption is about average for urban consumption in the United States (100 gallons per person per day) and the per meter consumption is considerably higher than that of St. Paul, Minnesota—Fargo, 563 gallons per meter per day and St. Paul at 327 per meter per day. The city requires an average of three and one-fourth million gallons per day or an average of about 108 million gallons per month.

For this supply the city draws its water from the Red River, having its intake in the river at the south end of the city or upstream. The water is ponded by a dam and thus provides a minor regulation in the flow of the

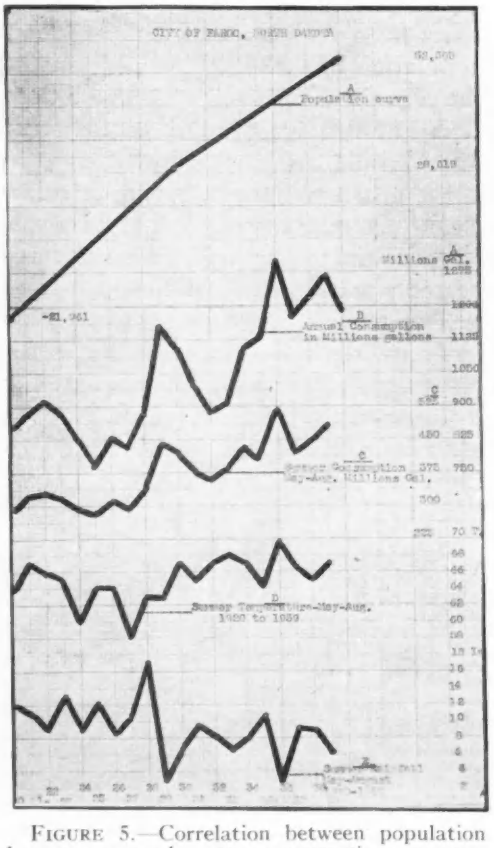
CITY OF FARGO, NORTH DAKOTA
Population curve
Millions Gal.
Annual Consumption in Millions Gallons
Summer Consumption May-Aug. Millions Gal.
Summer Temperature-May-Aug. 1900 to 1939

FIGURE 5.—Correlation between population increase, annual water consumption, summer water consumption, summer temperatures, and summer rainfall.

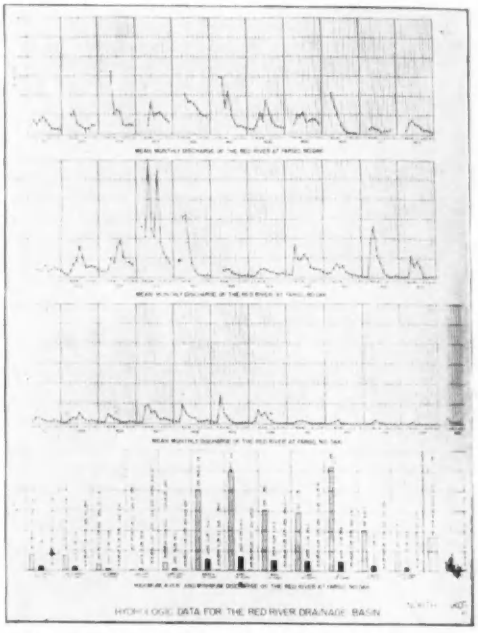

FIGURE 6.—Hydrologic data for the Red River Drainage Basin (reprint) showing discharge of Red River at Fargo, North Dakota.

TABLE IX

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	Population 1940	Gallons Consumed 1939	Gals. per Day per Person	No. of Meters	Gals. per Day per Meter	Source of Supply	Well Depth in Feet	Sewage Disposal
Minnesota—Bois des Sioux Sub-basin								
Browns Valley	1,075	6,000,000	15	130	126	Three wells One spring	200–400 25	Septic tank
Donnelly	370	No record	No record			Well	150	No report
Elbow Lake	1,150	25,400,000	60	400	174	Well	222	Septic tank
Herman	703	No record	No record			Well	150	No report
Wheaton	1,700	19,681,650	33	488	116	Well	149	None
Totals	[a]4,998	51,081,650	Number using wells....5 Number wells used....7 Number of springs....1			.....	.....	2 treatments
Average	.....	.....	36	...	138	.....	213	.....
Percentage	[a]2.2% of incorporated population [a].9% of total population							

river and constitutes a small immediate reserve. Nevertheless, this small reserve in the drought years of 1930–40 has been the only visible water supplying the mains of Fargo. No replenishment from stream flow occurred for weeks at a time.

In relation to the limited reserve of water supply, W. P. Tarbell, city engineer of Fargo, North Dakota reports: "In the summer of 1932 the total supply available to the city of Fargo was confined in a small pool held by a dam in the Red River. For a period of 81 days and, notwithstanding the strictest rationing, the draft exceeded the inflow into the pool with the complete exhaustion of the water supply a constant threat. From July 25, 1932, to date, there have been 749 days with *no flow* past the cities of Moorhead, Minnesota and Fargo, North Dakota (20 per cent of the time interval) with additional protracted periods of practically no flow." . . . "The United States Geologic Survey (1932–1938) shows average monthly flows of 300 million to 2,500,000,000 gallons, but there has been eighteen months of absolutely no flow past the two cities."

A reprint of the mean monthly discharge chart for the Red River at

TABLE X

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	Population 1940	Gallons Consumed 1939	Gals. per Day per Person	No. of Meters	Gals. per Day per Meter	Source of Supply	Well Depth in Feet	Sewage Disposal
Minnesota—Snake-Roseau Sub-basin								
Argyle	857	No record		No record		.....	.....	No record
Greenbush	556	No master meter		45	...	Well	185	No record
Hallock	1,353	25,000,000	50	...	...	Two rivers	.....	No report
Roseau	1,775	16,965,000	26	260	179	Two wells	90–100	Disposal plant
Stephen	673	No record (just organized)				Stream	.....	Disposal plant
Warren	1,639	32,000,000	53	600	146	Three wells	130	Septic tank
Totals	[a]6,853	73,965,000	Number using wells....3 Number wells used....6 Number of rivers....3			....	.....	3 treatments
Average	.....	.....	43	...	162	.....	127.5	
Percentage	[a]3.1% of incorporated population [a]1.3% of total population							

TABLE XI

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	*Population 1940*	*Gallons Consumed 1939*	*Gals. per Day per Person*	*No. of Meters*	*Gals. per Day per Meter*	*Source of Supply*	*Well Depth in Feet*	*Sewage Disposal*
				Minnesota—Buffalo-Wild Rice Sub-basin				
Ada	1,938	9,513,300	13	462	56	Three artesian wells	255	Imhoff tank
Barnesville	1,075	Consumption not reported		260	...	Three artesian wells	80 180 150	Activated sludge
Dilworth	1,068	No record at present				Artesian wells	154–157	Moorhead system
Fertile	907					No data		
Halstad	570	No separate meter (Flat rate of $1.00 per month)				Two artesian wells	290	Sewer to Red River
Hawley	1,128					No data		
Hendrum	341	No record of consumption ($6.00 flat rate per year)				One well	285	Sewer to river
Lake Park	654					No data		
Mahnomen	1,429	No master meter (Flat rate of $1.00 per month)				Artesian well	100	Sewer to river
Moorhead	9,491	249,897,169	72	1,842	377	Six deep wells	240–273	Activated sludge
Ogema	328					No data		
Rothsay	415	No records	(New system) (Flat rate)			One well	167	Cess pool
Shelly	344	No record				Artesian well	.....	None
Twin Valley	844	3,250,000	(All service not metered)	200	...	Three wells	150 250	Cess pool
Ulen	562	No meters in system (Flat rate of 50 cents per month)				Well	160	Not reported
Totals	[a]21,088	262,660,469	Number of wells....11 Number wells used....23			.....	.....	6 treatments
Average	.....	.....	42.5	.....	216	.....	192	.....
Percentage		[a]9.6% of incorporated population [a]4.1% of total population						

Fargo, North Dakota (Figure 6) taken from the report of the North Dakota State Planning Board certainly emphasizes the import of Mr. Tarbell's statement. The Red River which formerly held ample water for navigation, not to mention city supply, had dwindled to a series of pools with little or no flow

TABLE XII

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	*Population 1940*	*Gallons Consumed 1939*	*Gals. per Day per Person*	*No. of Meters*	*Gals. per Day per Meter*	*Source of Supply*	*Well Depth in Feet*	*Sewage Disposal*
				Minnesota—Otter Tail Sub-basin				
Battle Lake	623	6,325,000	28	127	137	Well	75	No public
Breckenridge	2,745	50,297,857	50	700	197	River	.....	None
Detroit Lakes	5,015	170,537,095	93	625	748	Lake	.....	Imhoff tank
Fergus Falls	10,848	339,030,000	85	1,817	511	Otter Tail River	.....	Partial
Henning	948	No record (Flat rate)	Unmetered			Well	.....	.....
New York Mills	771	1,500,000	53	125	328	Reservoir	.....	Municipal plant treated
Pelican Rapids	1,560	7,000,000	12	226	85	Deep well	115	Simplex aerator
Underwood	353	No record (just installed)		80	...	Well	140	No public
Totals	[a]12,015	574,689,952	Number using wells....4 Number of wells....4 Number using river....2 Number using lake....1 Reservoir....1			.....	.....	4 treatments
Average	.....	.....	53	.....	334	.....	110	.....
Percentage		[a]5.4% of incorporated population [a]2.3% of total population						

TABLE XIII

TABULATION OF WATER SUPPLY AND CONSUMPTION BASED ON QUESTIONNAIRE RETURNS, 1940

City	Population 1940	Gallons Consumed 1939	Gals. per Day per Person	No. of Meters	Gals. per Day per Meter	Source of Supply	Well Depth in Feet	Sewage Disposal
Minnesota—Red Lake Sub-basin								
Bagley	1,241	14,240,000	31	130	300	Two wells	140–175	None at present
Black Duck	753					No data		
Crookston	7,161	218,578,000	83	1,521	393	Red Lake River	.....	Sewage to river
East Grand Forks	3,511	73,300,000	57	294	683	Red Lake River	.....	River disposal
Erskine	581					No report		
Fosston	1,271	No record (flat rate)		Unmetered		.....	.....	.....
McIntosh	903	500,000*	10*	.....	...	Well	.....	.....
Oklee	414	No record				Well	278	No report
Red Lake Falls	1,536	19,060,300	34	276	189	Well	175	None at present
Thief River Falls	6,019	133,338,000	60	1,049	348	Red Lake River	.....	Pre-clar. trick filter
Totals	[a]23,384	458,516,300	Number using wells....4 Number wells used....5 Number using river....2			.....	.....	1 treatment
Average	.....	.....	43	.....	307	.....	192	.....
Percentage			[a]10.6% of incorporated population of basin [a]4.5% of total population of basin					

*Data not verified hence, not computed.

between. The relation of this flow to the declining rainfall in the basin is considered later. This discharge chart (Figure 6), of the mean monthly flow shows that with the exception of a slight spring freshet there was little to no flow during the balance of the year from around 1930 to 1940. A series of pictures (Figures 7 and 8) shows this sequence of flow from the spring freshet dwindling down to a mere pool by midsummer when the city used more water than the river flow replenished. As the flow diminished and the pool above the dam became stagnant the quality of the water also deteriorated. Heavy rains since 1940 have maintained a constant heavy flow and abundant water supply.

From the intake in the river the water is pumped to the filtration plant where it is filtered, treated, and then pumped to the water towers (Figure 9, plates A, B, and C).

The problem of supplying the city of Fargo with water is not alone in the diminishing stream flow of the Red River but also in its increasing population with its large per capita consumption per day (Table XVII).

The city of Fargo was organized in 1875 and has grown steadily—the population by decades and number and percentage of increase is noted in Table XVII.

The table of the growth of Fargo shows the rate to be declining but it also shows an increase of 3,961 persons in

TABLE XIV

CITIES IN THE BOSTON METROPOLITAN WATER SUPPLY DISTRICT

Name	Population 1930	Consumption in Gallons per Day	Gallons per Person per Day
Arlington	36,094	2,218,000	61
Belmont	21,748	1,373,000	63
Boston	781,188	87,868,000	112
Chelsea	45,816	5,808,000	127
Everett	48,424	4,429,000	91
Lexington	9,467	703,000	74
Malden	58,036	3,923,000	67
Medford	59,714	3,598,000	60
Melrose	23,170	1,569,000	67
Milton	16,434	891,000	54
Nahant	1,654	259,000	156
Quincy	71,986	.....	...
Revere	35,680	2,264,000	63
Somerville	103,908	8,696,000	83
Stoneham	10,060	712,000	70
Swampscott	10,346	893,000	86
Watertown	34,913	2,160,000	61
Winthrop	16,852	1,195,000	71
Totals	1,385,487	128,559,000	...
Annual	.....	46,924,035,000	...
Average	.....	.....	81 gallons

TABLE XV

PUBLIC WATER SYSTEMS OF CITIES AND VILLAGES WITH WATERWORKS FOR THE NORTH DAKOTA SIDE OF THE RED RIVER BASIN

Selected from table on page 269 of Water Supply Bulletin 598

Town	*Source of Water*	*Reservoirs*	*No. of Taps*	*Percentage of Population Supplied*	*Estimated Average Daily Consumption (Gallons)*
Abercrombie	Artesian well	Air pressure tank	....	...	.....
Anamoose	Well	Elevated tank	....	32	10,000
Ayr	Rain water	Elevated tank	....	...	.....
Casselton	Two artesian wells	Standpipe and cisterns	....	...	.....
Cooperstown	Two wells	Elevated tank and two reservoirs	80	25	35,000
Enderlin	Well	Elevated tank and cistern	....	70	50,000
Fairmont	Artesian well	Elevated tank and reservoir	....	...	.....
Fargo	Red River (filtered)	.....	3,000	80	2,300,000
Grafton	Four artesian wells	.....	....	...	.....
Grand Forks	Red Lake River (filtered)	Reservoir	2,350	90	900,000
Hankinson	Artesian wells	Tank and reservoir	....	...	175
Hannaford	Creek	Reservoir and tank	....	...	200
Harvey	Two wells	Two elevated tanks	135	25	60,000
Hillsboro	Wells	Reservoir	102	20	6,500
Langdon	Two wells	Tanks	....	75	37,000
Larimore	Well	Two reservoirs	....	...	.....
Lidgerwood	Artesian wells	Elevated tank and reservoir	140	75	.....
Lisbon	Artesian wells	Elevated tank	....	80	30,000
Litchville	Artesian well	Cistern	.....	...	.....
McClusky	Well	Elevated tank	....	...	.....
McVille	Well	Reservoir and cisterns	....	...	.....
Mayville	Goose River	Elevated tank	....	50	70,000
Park River	Two wells	Elevated tank and reservoir	....	...	.....
Rugby	Well	Elevated tank	75	50	52,000
Sheldon	Artesian well	.....	....	...	.....
Valley City	Well	Elevated tank	360	75	265,000
Wahpeton	Well and Ottertail River (filtered)	Elevated tank	575	100	300,000
Walhalla	Well	.....	.....	...	.....

the past decade to 1940 and this means an additional consumption of 396,100 gallons of water per day. The prospect of such an increasing consumption of water and the provision for it constitutes the most serious problem confronting the city of Fargo at the present time.

In addition to periods of declining

TABLE XVI

FARGO, NORTH DAKOTA, MONTHLY WATER CONSUMPTION IN MILLIONS OF GALLONS

Year	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
1920	72.6	66.5	70.5	65.3	65.4	72.3	75.4	78.4	72.8	71.7	70.4	69.9
1921	67.2	60.3	65.8	65.2	75.5	80.1	82.8	81.7	73.8	73.9	70.6	70.2
1922	67.7	61.6	68.3	64.9	73.3	79.7	83.0	96.3	86.4	78.4	74.5	75.9
1923	74.1	66.1	81.0	68.0	78.7	80.7	82.1	78.1	74.6	74.4	65.7	64.7
1924	65.5	59.2	63.4	63.4	65.8	75.5	76.4	72.8	68.0	69.2	71.4	78.8
1925	68.3	52.3	56.9	55.1	67.8	59.8	66.4	85.9	67.0	62.5	60.9	59.4
1926	58.5	52.2	59.4	67.1	78.1	73.9	91.3	71.9	69.1	72.7	71.2	59.9
1927	60.4	54.8	59.8	59.3	59.9	69.2	75.4	85.2	73.0	77.1	71.1	69.1
1928	67.5	61.8	68.5	62.7	85.9	92.6	76.6	83.9	68.3	76.4	71.6	71.7
1929	71.1	69.0	77.8	71.1	86.0	113.4	123.0	120.1	95.9	85.1	82.4	79.4
1930	73.3	69.5	73.9	71.6	79.2	99.9	123.4	120.1	92.1	81.4	72.4	73.0
1931	75.1	64.6	69.9	74.4	88.1	97.6	97.8	92.4	83.8	75.4	68.6	70.3
1932	61.0	64.4	66.7	68.5	76.7	90.0	108.6	86.2	72.5	68.4	62.1	64.3
1933	50.2	50.4	61.4	56.2	66.1	108.6	97.1	112.0	82.5	83.0	64.2	74.7
1934	69.2	63.9	73.6	69.4	116.1	86.2	124.5	107.4	83.9	86.8	76.4	78.6
1935	76.6	79.8	77.0	73.8	88.8	86.6	117.6	109.0	89.5	87.7	83.5	84.5
1936	87.4	87.9	95.3	91.8	109.5	133.7	157.3	123.3	101.9	96.4	79.4	80.1
1937	71.8	65.6	74.6	76.8	94.5	90.0	118.2	113.0	99.9	95.1	93.5	84.1
1938	82.2	77.3	84.3	86.3	81.5	100.5	126.6	139.3	94.5	96.3	90.3	84.4
1939	82.1	76.7	95.0	94.5	123.4	101.3	141.6	117.2	108.8	88.6	85.0	78.9
1940	75.6	70.5	73.6	75.4	96.1	109.3	142.0	127.0	106.1	88.7	80.6	76.6

rainfall and diminishing stream flow, some other natural items relating to the water supply problem for Fargo are shown in Figure 5. The curve A shows the steadily increasing population—1928–1940; B, the mounting annual water consumption in millions of gallons 1920–1940. But the fact that the curve showing the annual consumption fluctuates so widely shows that factors, other than the increasing population, play a part in the consumption. Of course it is realized that this fluctuation could be due in part to economic as well as natural factors as, for instance, a variation of industrial activity, the restriction of use by the city, or the stoppage of loss from leaking mains. Nevertheless, the curves C, D, and E do show that temperature and rainfall of the summer months play a prominent part. The summer months were chosen for this correlation since they represent the period of greatest use of water and would most likely show the effect of climatic influences. Figure 10 shows that the average water consumption in July is almost twice that of the average February. Curve C (Figure 5) shows that the total summer consumption for the months of May, June, July, and August follows almost exactly the trend of the annual consumption and furthermore, constitutes about 50 per cent of the annual consumption. Curves D and E (Figure 5) show the average temperature and the total rainfall respectively for these same months—1920–1940. From a comparison of the

TABLE XVII

POPULATION GROWTH OF FARGO

Year	*Population*	*Number of Increase*	*Per Cent Increase*
1880	2,693	.....	.....
1890	5,664	2,971	110.
1900	9,589	3,925	69.3
1910	14,331	4,742	49.5
1920	21,961	7,630	53.2
1930	28,619	6,658	30.3
1940	32,580	3,961	13.8

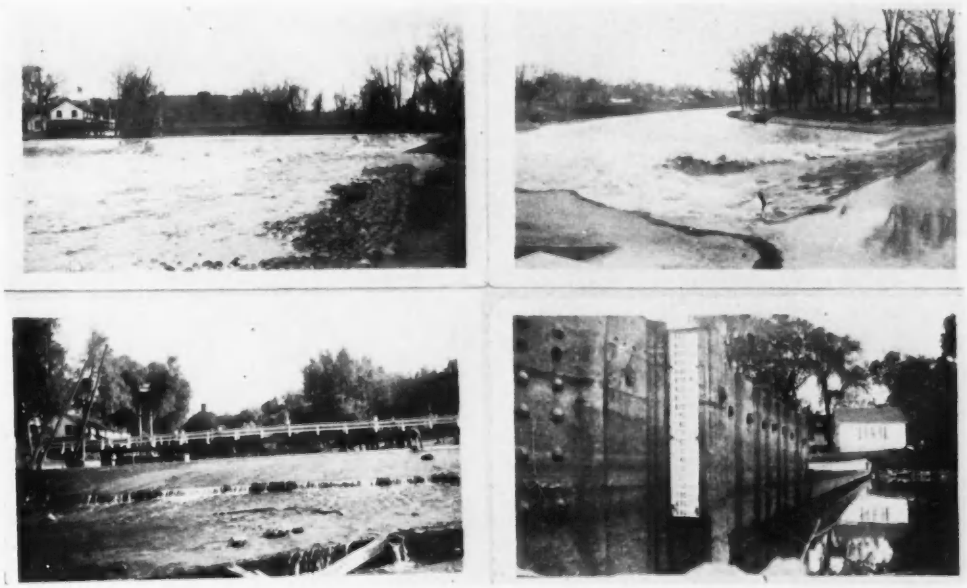

FIGURE 7.—Plates A and B above, show the Red River at Fargo, North Dakota. Spring freshets of 1936 left and 1939 right.

Plate C shows river flow dwindled to a trickle over the dam late in August 1940.

Plate D shows that the water has ceased to flow with the gage revealing a stage below the numerals in September 1940.

four curves B, C, D, and E one feature is consistently evident—that when a summer is both hot and dry the water consumption increases excessively. The hot and dry summer of 1929 caused a jump in consumption from 888,000,000 gallons in 1928 to 1,074,300,000 in 1929 in annual consumption.

Tables XVIII, XIX, and XX show further verification of this climatic effect in the month of May 1929. It was both wetter and cooler than 1928 with a corresponding decline in water consumption. But the markedly hotter and drier months of June, July, and August 1929 show an increase of water consumption of 111 million gallons over 1928. This tremendous addition to water consumption is undoubtedly due to heat and drought. This demand for more water comes when the flow in the Red River is at a minimum and certainly aggravates the problem of water supply.

The hottest and driest period on record, that of the summer of 1936 with its all-time high in water consumption for Fargo, emphasizes the seriousness of this climatic relationship to water consumption. The efforts and recommendations of the city officials in charge of water supply for Fargo have been directed toward the problem of a reserve supply. The new sewage disposal plant treats the sewage and returns the water to the river to replenish the downstream flow from Fargo northward.

FIGURE 8.—Plate C is a view downstream from the dam after the water has ceased to flow. Plate D is a winter scene of the pool above the dam. The river is completely encased in ice during the winter.

The city of Moorhead, Minnesota is the largest of the urban centers in the Red River Basin depending wholly on well water for its supply (Figure 11, plates A, B, C, and D). The water supply is furnished by six wells from 240–273 feet deep. These wells are operated by six Pomona deep well pumps having a capacity of 2,700 gallons per minute or nearly four million gallons a day. Since the highest month's pumpage on record was in July 1936 at an average of 1,133,000 gallons per

TABLE XVIII

MOORHEAD, MINNESOTA STATION, TOTAL SUMMER RAINFALL—MAY-AUGUST

Year	May	June	July	August	Total
1920	2.53	5.89	2.92	1.33	12.67
1921	2.56	1.40	3.08	3.94	10.98
1922	3.94	2.93	1.65	0.74	9.26
1923	1.85	6.73	2.34	2.83	13.75
1924	0.78	4.37	1.25	2.99	9.39
1925	1.98	5.62	4.35	0.25	12.20
1926	1.93	2.09	2.92	1.83	8.77
1927	3.63	4.28	1.01	2.02	10.94
1928	0.46	3.13	7.17	6.42	17.18
1929	1.13	0.30	0.94	0.75	3.12
1930	2.68	2.70	0.48	0.92	6.78
1931	1.95	2.79	5.19	1.85	11.78
1932	2.05	2.16	1.36	2.48	8.05
1933	1.93	2.13	1.44	1.34	6.84
1934	1.15	3.93	0.80	2.16	8.04
1935	1.81	3.01	2.13	4.59	11.54
1936	1.22	0.48	0.42	0.96	3.08
1937	1.37	1.89	2.68	3.59	9.53
1938	3.60	1.04	1.96	2.59	9.19
1939	0.48	3.92	0.43	1.49	6.32

TABLE XIX

MOORHEAD, MINNESOTA STATION, MEAN MONTHLY AND AVERAGE TEMPERATURE—MAY-AUGUST

Year	May	June	July	August	Average
1920	55.6	64.8	69.0	68.4	64.4
1921	56.6	70.4	72.8	68.2	67.0
1922	59.5	65.6	67.3	71.4	65.9
1923	55.8	68.1	72.5	63.9	65.0
1924	46.8	61.2	66.6	66.4	60.2
1925	53.2	64.4	68.2	70.7	64.1
1926	60.2	60.2	70.2	66.6	64.3
1927	49.9	62.7	66.0	64.6	60.8
1928	59.1	60.2	69.3	67.2	63.9
1929	50.6	64.0	71.5	69.8	63.9
1930	53.4	69.0	73.6	72.2	67.0
1931	53.2	69.0	72.5	67.6	65.5
1932	57.0	68.9	72.1	70.7	67.1
1933	56.8	72.8	73.7	69.5	68.2
1934	63.6	66.2	72.5	67.5	67.4
1935	51.6	61.9	75.6	68.6	64.4
1936	62.2	65.6	80.2	71.6	69.9
1937	58.0	63.6	72.1	74.2	66.9
1938	52.5	64.8	71.2	72.5	65.2
1939	62.2	64.4	72.8	70.5	67.4

day, the capacity of the supply appears ample for some time, unless of course, the wells become exhausted.

The city now has a large million gallon reserve tank in operation in connection with the three newer wells which will be of great service in smoothing out the pumping load (Figure 12). The water is pumped to the water tower and used directly without filtration. The three older wells have a storage tank of 200,000 gallons capacity. The two storage tanks should provide a day's reserve supply not including the water in the tower (Figure 13, plates A, B, and C).

The city's water system has grown from two miles of water main and no meters in 1900 to 30 miles of water main and 1,842 meters. The population growth was slow at first but the city had 4,840 people by 1910 and now has almost exactly double that number—1940 population being 9,491.

The annual consumption of water in 1902 was just over 102,000,000 gallons and changed very little until the drought year of 1910 when it jumped from 122 million gallons in 1909 to 160 millions in 1910. Regardless of population increase this 1910 figure was not reached again until the dry cycle of 1929–40 appeared. In 1932 the consumption

FIGURE 9.—Plate A top, shows the filtration plant for purifying the Red River water for Fargo, North Dakota.

Plates B and C show the main water tower in central Fargo and the supplementary tower in North Fargo, respectively.

TABLE XX

FARGO, NORTH DAKOTA, TOTAL SUMMER WATER CONSUMPTION IN MILLIONS OF GALLONS—MAY-AUGUST

Year	May	June	July	August	Total
1920	65.4	72.3	75.4	78.4	291.6
1921	75.5	80.1	82.8	81.7	320.2
1922	73.3	79.7	83.0	96.3	332.4
1923	78.7	80.7	82.1	78.1	319.7
1924	65.8	75.5	76.4	72.8	290.6
1925	67.8	59.8	66.4	85.9	280.1
1926	78.1	73.9	91.3	71.9	315.3
1927	59.9	69.2	75.4	85.2	289.8
1928	92.6	85.9	76.6	83.9	339.1
1929	86.0	113.4	123.0	120.1	442.7
1930	79.2	99.9	123.4	120.1	422.8
1931	88.1	97.6	97.8	92.4	376.0
1932	76.7	90.0	108.6	86.2	361.6
1933	66.1	108.6	97.1	112.0	384.0
1934	116.1	86.2	124.5	107.4	434.3
1935	88.8	86.6	117.6	109.0	402.2
1936	109.5	133.7	157.3	123.3	523.9
1937	94.5	90.0	118.2	113.0	415.8
1938	81.5	100.5	126.6	139.3	448.0
1939	123.4	101.3	141.6	117.2	483.7
1940	96.1	109.3	142.0	127.0	474.4

reached 177 million gallons and 1936 for the first time surpassed the 200 million mark at 212,820,000 gallons. The consumption was 204 million and 214 million respectively for 1937 and 1938 and then reached an all-time high of 250 million gallons in 1939. Even with the higher annual consumption of 1939, that of July, 1936 was higher than that of July, 1939—being 35 million gallons and 32 million gallons respectively. It is worth noting that July 1936 was the hottest and driest July ever recorded at Moorhead. The effect of heat and drought is certainly apparent since water consumption for this July was the highest on record. While July 1939 was practically as dry, it averaged eight degrees cooler (Tables XVIII, XIX, XXI, and XXII).

Moorhead ranked seventh in 1939 among the urban centers of the basin in consumption per person per day having 72 gallons as compared with 100 gallons per person per day for Fargo—the highest figure in the basin.

The difference in consumption between Fargo and Moorhead is very likely rooted in the extent of industrial use of water. The huge Fairmont Creamery plant in Moorhead supplies its own water from private wells and thus reduces the consumption considerably. If the consumption of the Fairmont Creamery were added, the average consumption per person per day would be around 110 gallons and the highest reported in the basin.

In addition to public, industrial, and domestic uses, the Moorhead water supply is used for irrigation by almost every resident with a lawn. As a rule the summer rainfall is too light or not sufficiently frequent to promote good lawn growth, especially, if the weather is hot. Hence, favored by the city with a special reduced rate or discount for water, above a certain minimum, used in watering lawns, most residents keep their lawns fresh and attractive by frequent or constant irrigation (Figure 15, plate A). Under this same provision many backyard gardens are also irrigated. This is likely one very important reason for the great summer increase in water consumption in all the organized systems in the basin.

The quality of Moorhead city water for domestic supply consumption is very highly regarded. This quotation is

TABLE XXI

MOORHEAD, MINNESOTA, MONTHLY WATER CONSUMPTION IN MILLIONS OF GALLONS

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1936	12.1	12.3	14.2	13.2	18.2	22.7	35.1	22.9	19.0	16.2	14.3	14.0
1937	14.2	13.4	14.1	14.4	16.1	17.7	22.1	22.4	18.7	19.2	16.6	15.0
1938	15.3	14.2	15.1	16.5	16.7	21.0	24.8	27.4	17.5	17.7	15.8	15.7
1939	15.9	13.9	16.8	15.9	26.4	22.8	32.7	29.2	27.2	16.2	16.5	15.9

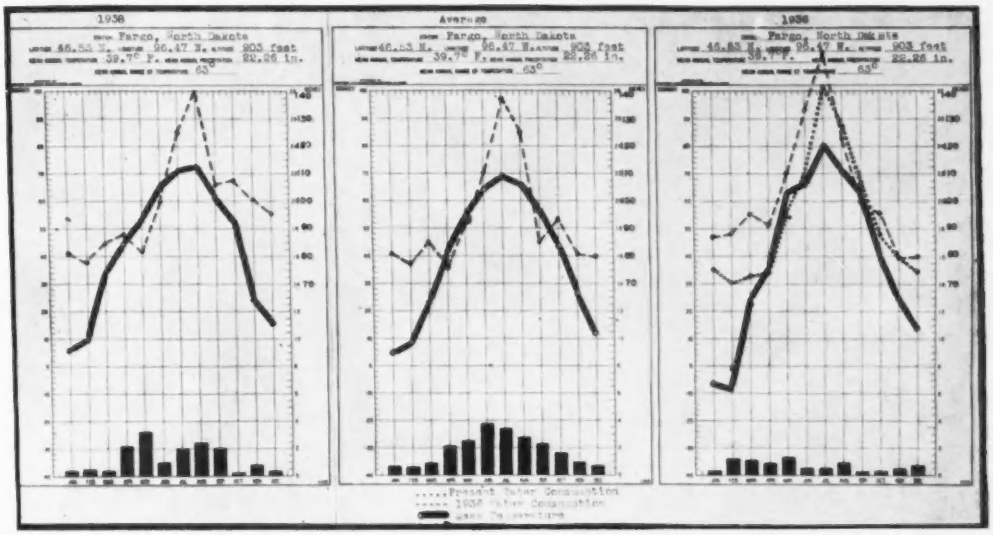

FIGURE 10.—Water consumption by months in millions of gallons for Fargo, North Dakota, average 1936 and 1938. Showing the relation between seasonal temperature change and water consumption. The summer months show a marked increase in water consumption. The year 1936 shows also that the hottest, driest weather has the greatest water consumption. 1936 had the greatest annual water consumption to date. The broken line shows average water consumption, 1938 and 1936. The dotted line shows consumption of 1939.

taken from the local press, "Chemical analysis has shown the water from the Moorhead wells to be as high chemical purity from the basis of domestic consumption as can be found anywhere in the United States."

The city of Moorhead has a new sewage disposal plant (Figure 14) and adds the water taken from the wells to the river flow after being purified in the sewage disposal plant (Figure 15, plates B, C, and D).

Grand Forks, North Dakota secures its water supply from the Red Lake River. It is the second largest city in the basin and has the second largest annual consumption of water. It ranks with the other larger cities of the basin in per capita consumption per day at 83 gallons. For the size of the city its consumption per meter per day is not high at 398 gallons. It is possible that not as many industries use city water as in Fargo or Fergus Falls, both of which rank well over 500 gallons in per meter consumption. The river water is not naturally pure and as at Fargo requires filtration and chemical treatment. The sewage however, is treated and the recovered water returned purified to the river. As is the case with Fargo, North Dakota and Moorhead, Minnesota, Grand Forks, North Dakota has shown steady growth as shown by table XXIII.

The increase in the last decade means again a heavier load on the water supply. At the rate of 83 gallons per day this added population means about 250,000 gallons more water per day or about 87 million additional gallons annually. Actually, the difference between the 1930 consumption of 524 million gallons and the 1939 consumption of 609 million gallons is just 85 million gallons. This emphasizes the extreme importance of the need of these cities to plan for a water supply for the future. Like Fargo, North Dakota, Grand Forks has enough water for the

TABLE XXII

MOORHEAD, MINNESOTA, ANNUAL WATER CONSUMPTION IN MILLIONS OF GALLONS

Year	*Millions of Gallons*	*Year*	*Millions of Gallons*	*Year*	*Millions of Gallons*
1902	102.1	1915	81.3	1928	123.3
1903	96.7	1916	79.2	1929	130.6
1904	90.1	1917	73.6	1930	143.8
1905	73.0	1918	68.3	1931	144.8
1906	99.9	1919	87.1	1932	177.8
1907	124.4	1920	91.8	1933	171.8
1908	112.4	1921	110.4	1934	169.0
1909	122.4	1922	106.7	1935	162.3
1910	160.8	1923	94.4	1936	212.8
1911	139.0	1924	100.8	1937	204.4
1912	151.3	1925	108.3	1938	214.9
1913	63.9	1926	112.2	1939	249.8
1914	68.9	1927	117.2		

present but has no reserve for the future growth of the city, either population or industrial expansion. With the recurrence of a dry cycle, dire consequences in water supply and use are sure to follow.

Grand Forks shows the same marked summer maximum in water consumption as Fargo and Moorhead and the same relation of increase in consumption with the hottest and driest weather. The year of 1936 was the Grand Forks all-time high in water consumption at 643,514,000 gallons, and July 1936 at over 66 million gallons represents the highest month. Their maximum day's pumpage of over three million gallons represents a heavy load on the water supply, particularly, when it occurs at a season when stream flow does not ordinarily replenish the city take of water.

Fergus Falls, Minnesota is the third largest city in the basin with a popula-

FIGURE 11.—Plate A above shows the three original artesian wells with storage tank supply for the city of Moorhead.

Plates B, C, and D show one of the three new wells with the new million gallon storage tank under construction in 1940.

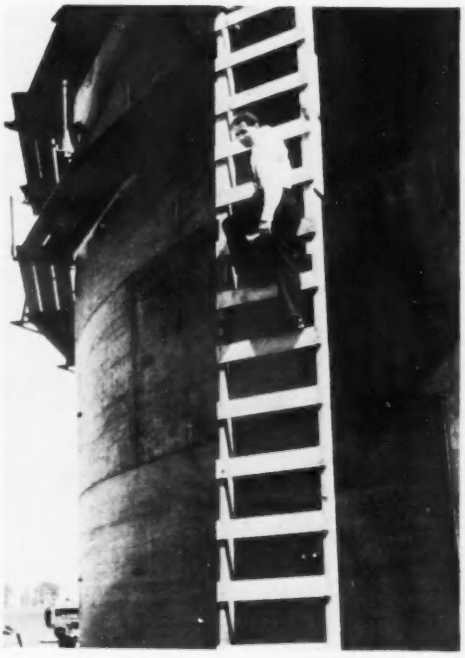

FIGURE 12.—The new million gallon storage tank for Moorhead, Minnesota which was completed in the late summer of 1940.

tion in 1940 of 10,848 and the third largest city in consumption of water at about 340 million gallons of water annually. Its per capita consumption of 85 gallons per day is in line with the other large cities of the basin. Its per meter consumption of 511 gallons per day is high suggesting probably industrial use of city water. The city draws its supply from the Otter Tail River (Figure 16) and it requires filtration and treatment. The city has partial treatment of sewage.

Fergus Falls has grown steadily but not quite as rapidly as the Red River Valley cities. In 1910 its population was 6,887; in 1920, 7,581; in 1930, 9,389; and in 1940, 10,848. The reported consumption, in their reply to the questionnaire by five-year periods shows, however, no corresponding increase in consumption—being 370 million gallons in 1930, 360 million gallons in 1935, and 339 million gallons in 1939.

The stream flow at Fergus Falls of the Otter Tail River shows the same marked decline since 1930 as has the Red River at Fargo. Up to 1930 the flow was usually at 200 second feet or markedly above. Since that time to 1940 the flow was only occasionally above 50 second feet. However, the city of Fergus Falls with its location near the lake country states that its water supply is ample and assures them of adequate future needs.

Valley City, North Dakota has grown steadily but has not shown as high a rate of increase as the cities in the valley and the eastern part of the basin. Its

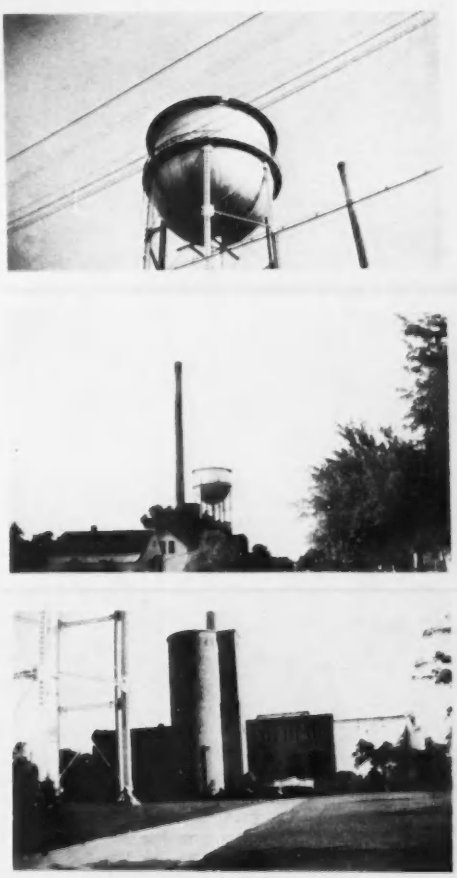

FIGURE 13.—The water tower and municipal electric light and power plant of the city of Moorhead, Minnesota.

FIGURE 14.—Red River Dam and early summer flow, June 1940, just south of Fargo–Moorhead, just above the Moorhead outlet of recovered sewage water wholly purified.

TABLE XXIII

GRAND FORKS, NORTH DAKOTA, POPULATION GROWTH

Year	*Population*	*Number of Increase*	*Per Cent Increase*
1880	* 1,705	.....	.....
1890	4,979	3,274	192.
1900	7,652	2,673	53.7
1910	12,478	4,826	63.1
1920	14,010	1,532	12.3
1930	17,112	3,102	22.1
1940	20,228	3,116	18.2

population in 1910 was 4,606; in 1920, 4,686; in 1930, 5,268; and in 1940, 5,917. The city draws its water from three wells in the valley alluvium at 50 feet in depth. The supply is stated as ample for present needs and possibly future developments. The city purifies its sewage restoring the recovered water to a gravel pit where it is naturally filtered again and replenishes their ground water supply.

The consumption of water has shown increase since 1930 at from 130 million gallons to 197 million gallons in 1940. As is the case with the other cities of the basin, the hot and dry year of 1936 shows the highest consumption at 181 million gallons with the exception of 1939. Summer is the season of maximum consumption with the month of July 1939 showing more than twice the amount used as compared to January 1939—January, 11 million gallons and July, 23 million gallons. June 1936 showed a monthly all-time high at 24 million gallons.

The other cities on river water supply

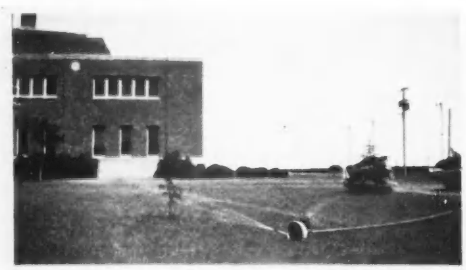

FIGURE 15.—Plate A shows the lawn irrigation system of Moorhead State Teachers College. The wheel rotates slowly and the system automatically covers a wide stretch of lawn.
Plates B, C, and D show the Moorhead sewage treatment plant which removes the solids.

FIGURE 16.—Fergus Falls, Minnesota and the Otter Tail River from which the city draws its water supply.

show the same relationships as these larger cities reported in detail. Like Fergus Falls, Minnesota, Thief River Falls, Minnesota reports water for future expansion. Crookston, however, on the same river (Red Lake River) reported insufficient supply for future growth of the city. The water supply for the city of Crookston is furnished by a private corporation.

This survey emphasizes that serious difficulties develop during dry cycles in supplying the larger cities in the Red River Basin with adequate water. Since the entire flow of the rivers was in use for city supply during the past dry cycle, no reserve will be available for the possible increased use of a future like-period. The situation calls for the most careful survey of the basin's water resources and the direction of these resources to critical points.

STORMS OF THE WORLD

Stephen S. Visher

STORMS have ever formed one of the most interesting features of man's environment. Throughout history they have disrupted his plans, from the time when he organized his hunts for the mammoth and the auroch to the campaigns of the global war. They have destroyed his structures and hindered his progress, and wrought havoc among his crops and his cattle. They have changed the face of the landscape about him. They have complicated his problems, confused his courses, modified his adjustments to his environment. They have given him a vast share of the moisture he needs for life, much of the power he has used for travel and industry. Storms are interesting.

Of the many kinds of storms all are cyclonic in origin but one, and that exception is associated with cyclonic disturbance. All storms are related to local differences in atmospheric temperature and the rotation imparted to the air by the earth's rotation. They vary in size from the tiny whirlwinds only a few yards in spatial dimension that whirl dust and leaves and cornstalks across the midwestern prairie lands to the great massive geodepressions in atmospheric pressure hundreds, even thousands of miles across. Intermediate storms are waterspouts, tornadoes, and tropical cyclones. The features of such storms form the subject matter of this paper, without definite intent or purpose of explaining their cause or detailed character.

THUNDERSTORMS

Most thunderstorms are minor, though important, features of the larger cyclonic disturbances—sort of local eddies. Although they are predominantly convectional rather than cyclonic, detailed studies have proved that convection sufficient or intense enough to cause thunderstorms almost never occurs except where the air is disturbed by at least a feeble cyclonic disturbance.

Thunderstorms are the most numerous type of storm with a world total of about 40,000 per average day, according to C. E. P. Brooks. They are most common in the rainy tropics, where each locality generally has one a day throughout most of the year and sometimes two or three. They are common in summer in the United States, where most localities have an average of one or two a week which pass at least within sight. In most subpolar regions, however, only a few occur, sometimes not a well developed one in a summer. Thunderstorms occur during every month of the year in tropical and subtropical regions, but are rare or absent during cold weather in regions with cold winters.

Most thunderstorms are only a few dozen miles across and as they commonly do not live to travel far, they affect only a relatively small area, often only a few hundred square miles. In the United States, however, they may travel a few hundred miles. Their average local duration is only an hour or two. Generally in the Westerly Wind Belt they travel in an easterly direction while in the Tradewind Belt, they commonly move westward. Their rate of average progress increases with the latitude; slow near the equator and usually 10–30 miles an hour in mid-latitudes.

Thunderstorms are significant in several respects. They form a major source of rainfall, cause a sharp drop in temperature, commonly have at least a little strong wind; their most distinctive feature is thunder, induced by lightning. Their cloud effects are noteworthy, some of the most imposingly beautiful seen anywhere. They often yield hail as well as rain. Altogether they are perhaps the most impressive atmospheric phenomenon commonly seen, highly useful in the aggregate, but locally often seriously harmful. The good they do, aside from the rain they bring to parched lands which often is highly welcome, includes the invigorating drop in temperature, the awe-inspiring display of cloud, lightning and wind, and the generally stimulating effect of the dramatic change of weather. The harm they do includes the squall wind, just before the rain falls. This gust often is violent enough to do considerable damage. The annual average property loss from "windstorms not tornadoes" in the United States is about $200,000,000. Much of this loss is due to thunderstorm squalls. Rain often falls torrentially, with the result that a large share of that which falls upon sloping ground runs away. Much of the soil erosion of our fields is due to thunderstorm rain. "Cloudbursts" not only cause erosion but they sometimes produce locally harmful floods. The lightning incidental to thunderstorms affords a spectacular display of usually harmless fireworks but also often does damage. Each average year more than five hundred people are killed by lightning in the United States. Many thousand livestock are also killed. Fires started by lightning annually destroy many million dollars worth of buildings and crops. Lightning starts many forest fires, some of which cause enormous losses. The lightning of thunderstorms does good as well as harm. Every flash combines some atmospheric nitrogen and oxygen to form ammonia, which when carried into the soil by rain adds fertility. Ammonia is an important source of increased fertility in the regions where thunderstorms are common. At the few stations where prolonged studies of this subject have been made, four to eight pounds per acre per year are added thus in England, six to eight in northeastern United States. Lightning flashes also create ozone, an unstable form of three oxygen atoms (O_3), instead of the stable two. Ozone has a pungent odor; some evidence indicates that it has a stimulating influence upon mental activity. Lightning is most dangerous at the beginning of the storm, just after the squall wind, when many lightning flashes travel downward. Later, lightning commonly is between parts of the storm or even upward from the ground.

Hail which falls in many thunderstorms is a convincing proof that the air is cold overhead even in hot weather. It also proves that the updrafts of air which make the imposing thunderhead are strong. Hail does much damage in various midlatitude regions and on tropical plateaus. In the United States the annual property loss reaches large figures. For example, detailed Federal estimates are that hail normally reduces the wheat harvest by some 15 million bushels, oats as much, and the corn harvest by some 24 million bushels. Considerable damage is also done to fruit, greenhouses, and poultry. Each year many people die in the United States as a consequence of hail bruises and annually some hundreds die thus in Europe, Asia, and on the plateaus of Africa.

Thunderstorms are most numerous in the doldrums or wet tropics. Many severe thunderstorms occur in Brazil,

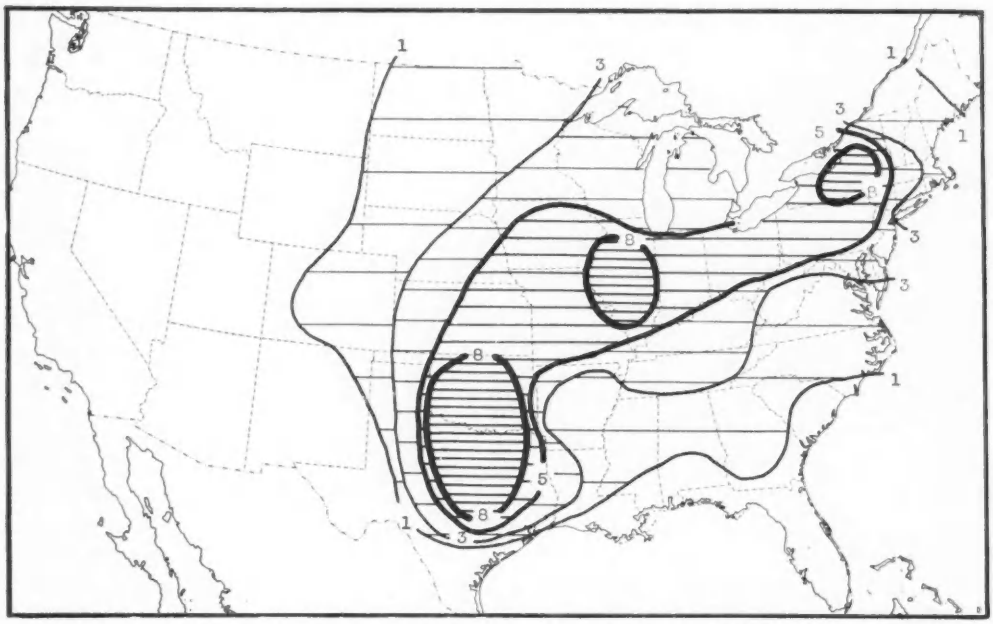

FIGURE 1.—Lightning losses to farm buildings. Annual average, $100,000 (after Kincer).

in the Congo basin of Africa, and in the East Indies. They are common throughout the rainy season in the parts of the tropics which have a wet season and a dry season, for example, the monsoon region of southeastern Asia and the Sudan of Africa. They are common during the summer months in the parts of the middle latitudes which have summer rainfall, for example in eastern United States, in Russia, and eastern Argentina. They occur occasionally in summer in subpolar regions and even in winter over the sea near Iceland. In the United States 60 to 80 thunderstorms occur in an average year in each locality in much of the Southeast, most in Florida, while 20 to 40 occur in most of the Northeast, and 20 to 50 in most of the West, except on the Pacific coast where there is little summer rainfall and hence few thunderstorms. Thunderstorms occur, however, in spring and autumn in the California type of climate; for example the vineyards of southern France suffer badly from hailstorms incidental to thunderstorms.

TORNADOES

Tornadoes, often called cyclones, are rare as compared with thunderstorms and are of minor importance, but in many cases they are so dramatically destructive that they attract undue attention. They are especially common and destructive in the United States; it is sometimes incorrectly stated that they are unique here. Typical tornadoes have repeatedly occurred in all the main parts of Europe, including England, in southern and eastern Asia, in Africa, and South America, while Australia according to the director of the Australian Weather Bureau has about as many per year (140) as the United States.

Tornadoes are violent tiny whirls started by opposing winds and associated with sharp vertical contrasts in temperature. They start in the clouds and extend to the ground only where the air near the surface is relatively warm, as compared with the higher air. Tornadoes rise above the surface again whenever the surface air is relatively

cool. Hence, as to time of day, destructive tornadoes occur chiefly in the afternoon or early evening. The few destructive nocturnal tornadoes occurred on hot sultry nights. Weather Bureau experts can successfully predict the general occurrence of tornadoes, but not their exact location. As they affect such a tiny fraction of the large area in which they might occur on any particular day, the benefits derived from official forecasts are more than outweighed by the suspension of business, fear and even heart failure forecasts induce.

Tornadoes are more than ten times as frequent near the center of the United States than in the Northeast or West. They are least common, however, in the most arid region, where violent almost tornado-like dust whirlwinds are frequent. In the approximately 2,800 tornadoes recorded by the Weather Bureau in the United States during the twenty years 1916–1935, 5,224 people were killed and property losses in excess of 230 millions of dollars were sustained. Losses in excess of $100,000 were caused by an average of about twenty tornadoes a year, losses in excess of $1,000,000 by about two. In that 20 year period, three caused losses of 24 to 43 millions of dollars each; one of these three and two others killed more than 100 people. The worst was that of May, 1925, chiefly in southern Illinois in which 689 lives were lost. The average American annual loss is 261 lives and about 12 million dollars worth of property.

Tornadoes have occurred in all of the States and Canadian provinces and in Alaska. They affect so small a strip (generally about a sixth of a mile wide by 10 to 30 miles long) that the chances that any spot will be hit are small. Even in the area where they are most common, the chances that an average farm will be crossed in a century are less than one in a thousand. Many farms are crossed without damage to the buildings; many buildings are demolished without the loss of a human life.

Hurricanes, Typhoons, and Lesser Tropical Cyclones

More than 200 tropical cyclones, of which some 40 have hurricane winds, develop annually over the tropical and sub-tropical oceans. They affect significantly more than one-fifth of the globe and the world's population.

Although destruction they cause is often terrible, tropical cyclones benefit a much wider belt than they devastate. They do this chiefly by bringing rainfall to large parts of the tropics which otherwise would be too dry. Few tropical cyclones are destructive; the weaker ones usually do little harm and much good. The terribly destructive type rarely occurs, except in the Far East. Distant or incipient cyclones set up air movements which induce convectional over-turning, giving rise to thunder storms. Much if not most of the rainfall of these latitudes is induced by cyclonic disturbances, weak or distant. Tropical cyclones as a class certainly do more good than harm.

Tropical cyclones are whirling storms which vary in intensity from mild disturbances to violent hurricanes; they average about 300 miles across, develop chiefly in latitudes 10–20°, and travel generally roughly westward, pushed by the Trade Winds. They also move into progressively higher latitudes until they die away or leave the tropics. If they reach midlatitudes, they slowly recurve and then are carried eastward by the prevailing Westerlies and become lows. Tropical cyclones usually travel rather slowly, generally only about ten miles an hour; the whirling winds about the

center, however, have velocities ranging from about 20 miles an hour to more than 75. A few have wind velocities measured about 150 miles per hour, while the destruction which some have caused indicated even greater velocities. The wind's destructiveness is due partly to its sudden variations in velocity and direction.

Tropical cyclones are often destructive because of the strength of their winds, the torrential rainfall, and on bodies of water, the high and tumultuous waves. Typhoons, the name applied to strong tropical cyclones in the Far East, cause the death of an average of several thousand persons a year, few years pass without the death of more than a thousand, while occasionally huge numbers die. For example on August 3, 1922 more than 30,000 were reported killed near Swatow, China, while the next year the death of over 100,000 in and near Tokio, Japan is attributed to the typhoon which prevailed during the fires started by the earthquake of September 1. In India few years pass without numerous fatalities and occasionally the toll is huge; indeed there are competent estimates that more than 200,000 persons were drowned on October 3, 1876, and about 300,000 on October 7, 1737, in the delta of the Ganges-Brahmaputra River, near Calcutta. In the West Indies and neighboring regions, the toll is several hundred a year on the average, when account is taken of the heavy losses in exceptionally destructive storms. For example about 2,000 persons were killed in and near New Orleans in 1893, 3,300 in Porto Rico in 1899, 6,000 in and near Galveston in 1900, and 2,500 in Porto Rico and Florida in 1928. In Martinique and near-by islands as many as 20,000 were officially reported killed by a hurricane in 1781. Cuba has had hurricane fatalities of 1,000 or more during a number of years, and in 1791, 3,000 were reported killed there. The hurricane which demolished most of the houses of the capital of Santo Domingo, on the

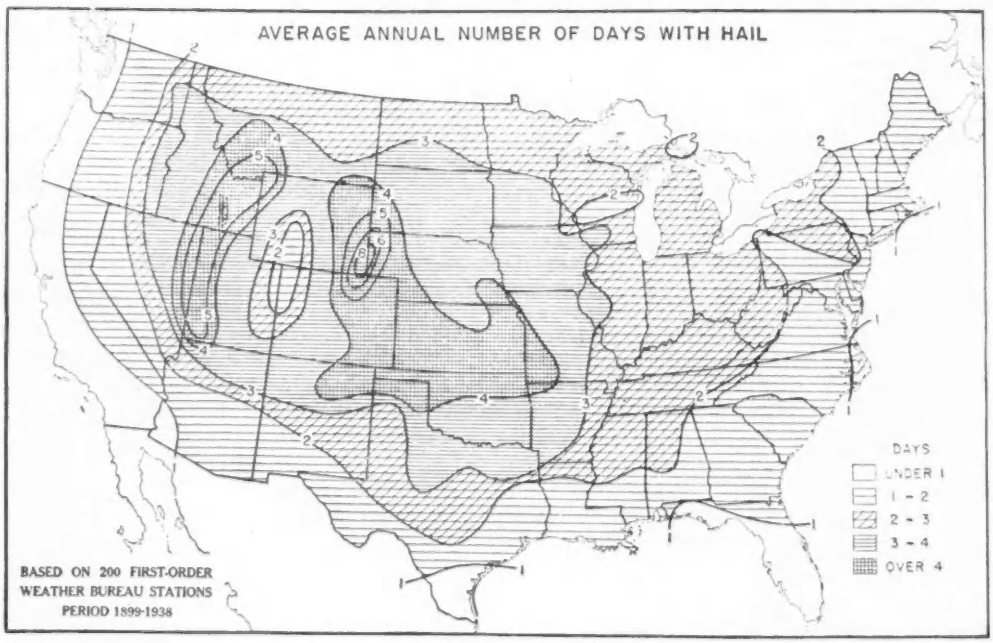

FIGURE 2.—Average annual number of days with hail (Yearbook of Agriculture 1941).

island of Haiti, on September 3, 1930, is reported to have killed about 4,000 people and done damage to property in excess of $40,000,000. Tropical cyclones that lack destructive winds often do serious damage by heavy rains, often more than 10 inches falling in a day and occasionally more than 30 inches in the two or three days as they pass. These deluges cause serious floods and severe soil erosion.

Tropical cyclones enter the United States chiefly from the West Indies and the Gulf of Mexico, but occasionally one progresses northward along the western coast of Mexico, affecting southern California or Arizona. Some storms which developed in the western Pacific (the Far East) as tropical cyclones (typhoons) also enter the United States from the northwest, as lows. Indeed a considerable share of our lows are of tropical origin. An average of about twenty cyclones a year enter the South or pass northward near the Atlantic coast. Of these, three on the average are hurricanes and two have gale winds (32–75 miles per hour).

Especially disastrous American hurricanes with the reported loss of life are as follows: 1881, August, coast of S. Carolina and Georgia, 500; 1893, August, coast of Carolina and Georgia, 1,000; 1893, October, New Orleans, etc., 2,000; 1900, September, Galveston, 6,000; 1915, August, Galveston, 280; 1915, September, New Orleans, 275; 1926, September, Florida-Mississippi, 399; 1928, September, Cuba, Florida, 3,000; 1935, September, Florida, 300; 1938, September, Long Island, New England, 682. American property loss was highest in the New England storm estimated at $400,000,000. The Galveston 1900 storm did an estimated damage of $30,000,000. The Florida hurricanes of 1926 and 1928 caused great tangible property loss, and in addition punctured the Florida boom, causing sharp decrease in real estate values.

Lows

The largest type of storm is the mid-latitude cyclone or low, of which somewhat more than a hundred occur each year in the United States and about as many in Europe, and produce an almost continuous change of weather. Other regions having many of these storms are the middle latitudes of Asia and the region around Antarctica, extending as far north as southern South America and southern Australia.

Lows have an average width of about 6.0 miles, ranging from about 200 miles to about 1,000 miles. They travel usually some 400–700 miles a day, two or three times as fast as an average tropical cyclone. Their normal wind velocity is about 10–20 miles per hour over the land, where ground velocities in excess of 30 miles an hour are rare. Over the North Atlantic and in the North Pacific, however, wind velocities of 40 miles an hour are common, and frequently cause seasickness to travellers

Lows are important for five chief reasons: 1) they bring rainfall to large and important regions which otherwise would be dry, for example, most of interior United States; 2) they bring our changes of weather; 3) they afford the basis of our weather forecasts; 4) they cause considerable destruction of life and property, and much inconvenience, by the winds, rains, hot waves, and by the thunderstorms and tornadoes associated with some of them; 5) the changes of weather are stimulating to mankind both directly and indirectly. The importance of this influence is suggested by the fact that the more progressive, civilized peoples are

in areas where numerous cyclonic storms cause frequent changes of the weather.

Lows of mid-latitudes are the great rain bringers of their region but many yield considerable rainfall only in the more humid sections of their paths. For example, in the United States, lows which cross from the Pacific to the Atlantic may yield no rainfall in the region between the Cascade-Sierre-Nevada and the Rocky Mountains, and only a little over the Great Plains. But as they enter the humid eastern half of the country, they draw moisture from the Gulf of Mexico, and yield increasing amounts of rain as they pass eastward. Conversely, lows which pass from the Atlantic Ocean into Russia and Siberia yield less and less rainfall as they pass farther and farther from a sufficient source of moisture. In Central Asia they may cause only cloudiness, or perhaps yield a few drops of rain, as similar storms do in crossing our Great Basin. They bring rain by drawing moisture from the sea (as a result of the inblowing winds) and especially by inducing condensation and precipitation by the convectional disturbance which they set in motion.

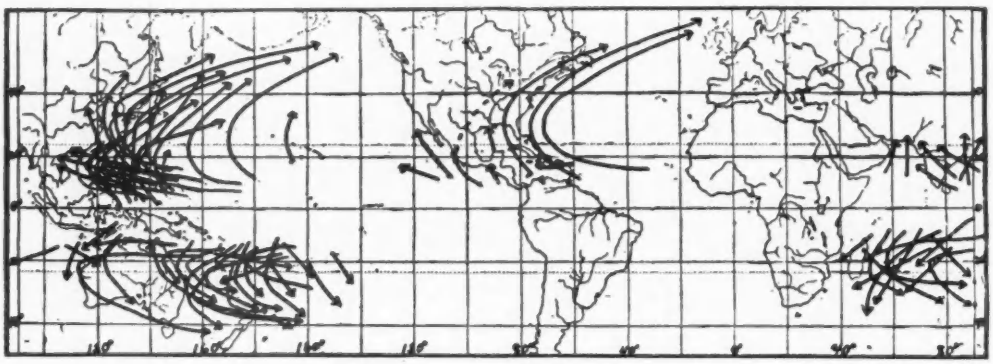

FIGURE 3.—Sketch map showing tracks of tropical cyclones (hurricanes, typhoons, and gale-producing cyclones) of an average year.

Lows bring our change of weather by altering wind direction and velocity, by inducing cloudiness and producing rain. They change the winds because the fundamental part of a low is an area of below-average air pressure into which wind blows spirally. Thus on the western side there are northerly winds, which are usually relatively cold as compared with the southerly winds which are characteristic of the eastern side. Therefore a cyclone approaching from some westerly direction first causes the temperature to rise conspicuously, and then, as the center passes, to fall rather sharply. The warming as the low approaches is due not only to the warm southerly winds, but partly to the liberation of latent heat by the condensation of part of the moisture they carry. Clouds which are formed interfere with the escape of the heat, and help make the nights relatively warm. Cooler northerly winds which prevail shortly after the center of the low passes produce first a dash of rain or snow and then a clearing of the skies, with much cooler nights.

Lows afford much of our basis for weather forecasting since most scientific weather forecasting is based on a study of the approaching lows. The forecasters attempt to predict when they will arrive and whether or not they will have characteristics they had previously. Many lows are altered as

they move eastward by the effect of other lows and highs. Their rate of advance eastward is not uniform and their courses are often changed. As a result, the forecasts are only approximately correct.

The general eastward movement of lows is due to the Westerlies, which prevail overhead most of the time in the United States, pushing the cyclonic masses east or east-northeast. That the highs move, in general, east-southeast instead of east-northeast, shows that the prevailing Westerlies are only one influence. The second influence is the result of the continual blowing of the Westerlies; air piles up in polar and subpolar latitudes. From time to time some of this air must return to lower latitudes or else finally much of the air would accumulate near the Poles. Our highs are masses of subpolar air which have broken away and are moving east-southeastward across the United States. A third, often highly significant influence which affects the courses followed by the lows is the air pressure conditions which prevail at the time in nearby areas.

Some Effects of Torrential Rains

Effects of heavy torrential rains resulting from severe thunderstorms are discussed in an article in the *Geographical Review*. Some extracts are relevant here. Buildings may be damaged by flooding of basements, weakening of foundations by runoff, and by water soaking. Buildings on lowlands may be partly submerged by the floodwaters of torrential rains. For example, the storm that brought 10 to 20 inches of rain in 24 hours to eight Weather Bureau stations in southeastern Alabama (March 14–15, 1929) flooded many towns. That rain caused an officially estimated damage of more than $3,750,000—not counting suspension of business.

City and town water supply, whether from shallow wells, reservoirs, or streams, and sewer disposal systems are seriously interfered with by torrential downpours. Heavy rainfalls injure roads, railroads, bridges, airports, and pipe lines by flooding, softening, and eroding. Although large-scale floods are caused by prolonged rains, the briefer storms often cause serious local floods. For example, on June 29–30, 1940, an estimated damage of $200,000 was done to roads, railroads and bridges in an area 50 miles by 100 miles in Texas, where from eight to 20 inches of rain fell in 24 hours and a number of people were drowned.

The damage to telephone, telegraph, and electric lines by torrential rains is partly due to the force of the water-laden winds that accompany most such downpours. But the damage is much increased by the softening of the ground caused by the large amount of water that runs down the poles. Electric light and power services may be disrupted by damage to the generating plant. If the plant is a hydro-electric one, the damage may be gradual, due to silting of the reservoir, or very rapid, due to breaking of the dam. Or the excessive rainfall may raise the water level enough to put the plant temporarily out of order. Fuel-powered plants, too, may suffer flood damage since their water requirements encourage location close to a stream.

Crops are damaged in several ways. Planting may be delayed; seeds and small plants may be washed out or buried beneath sediment; growth of weeds is facilitated, partly because cultivation is hindered. The value of unpicked cotton is greatly diminished when the open bolls are soiled with mud spattered by a hard rain.

The most serious long-term damage by torrential rains is that done by erosion and leaching. The South, where such rains are most frequent, is the large American region where soil erosion is most serious. Except for Florida and the low-lying land along the coast, fully four-fifths of the South has widespread "serious" or "harmful" erosion. By contrast, less than one-third of the North has either. It is obvious that the relatively extensive soil erosion in the South is due in part to the greater and more frequent hard rains.

CYCLONIC STORMS AND CIVILIZATION

The correspondence between the distribution of cyclonic storms and civilization has been discussed at length by Ellsworth Huntington in his "Civilization and Climate", "Principles of Human Geography" and "Mainsprings of Civilization." One-tenth or so of the land which has many lows is far ahead of the rest of the world in many respects. Analyses of production per worker, high achievements, and death rates have led Huntington to conclude that the main influence is the frequent change of weather. The many drops in temperature are stimulating, but also important are the many complications these storms impose. These call for continual adjustment. The many storms also insure a supply of moisture which is fairly dependable, as compared with that received in most of the world, despite the fact that the cyclonic regions have floods and drouths. People of Cyclonic Regions not only produce relatively large amounts of goods but lead in thriftiness, inventiveness, and in preparations for the future. The much disliked irregularity or uncertainty of the weather characteristic of cyclonic regions presumably has encouraged this forethought. In the parts of the world where weather changes are relatively few, people much more commonly "trust to luck."

Unquestionably the stormy regions now dominate most of the rest of the

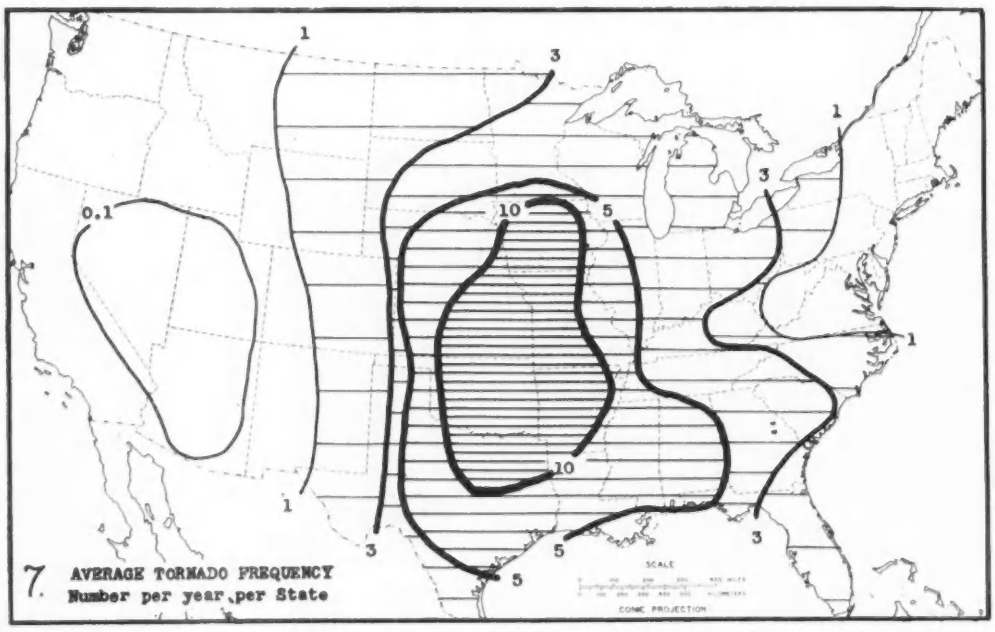

FIGURE 4.—Average tornado frequency in the United States (Scientific Monthly).

world politically, economically, and culturally. Two thousand years ago the regions which are now dominant were then of secondary importance is due perhaps partly to the fact that modern man, with the help of coal, glass, steel, and goods made from them, can now live with fair comfort in stormier and more stimulating regions than could primitive man. Possibly also the Mediterranean lands formerly were stormier than at present. That there have been great changes of climate since man appeared is proved by the great glacial ice sheets which accumulated and disappeared since then.

AGRICULTURAL ECONOMY OF THE LAGUNA REGION

Lorene A. Garloch

A LARGE, rather irregular shaped basin surrounded by arid ranges forms the Laguna Region, which lies between 25° 30′ and 26° 20′ north latitude and 102° and 104° west longitude. Approximately 125 miles north of the Tropic of Cancer, it straddles the states of Durango and Coahuila. Covering a vast expanse of level ground, it extends on both sides of the Nazas River from 24 miles southwest of the city of Torreón to the depression of the Laguna de Mayran in the east; from the river Aguanaval in the south to the Tlahualilo section in the north. These two rivers which traverse the region make agriculture possible in this semi-arid basin.

Agriculture is by far the most important activity in the Laguna Region. Land is fertile and water is available. The amount of water delivered into the Laguna Area is greater than that at any other place in the interior basins of northern Mexico. This is, therefore, the natural basis for the greatest irrigated district in the northern plateau. The run-off from the 30,000 square miles of mountains, the greatest area of high mountains in the northern plateau, is accumulated and carried down by two rivers, the Nazas and the Aguanaval. The water is then distributed by a network of canals over the plain.

Of the two streams mentioned, the most important is the Nazas. It has a large basin impounding a great deal of water which makes it the main supply of the precious liquid upon which depends the prosperity of the Region. It is more or less seasonally regular in its volume of water and is regular in its inundation. The same cannot be said of the Aquanaval whose floods are scarce and extremely irregular. This river is of a torrential nature but the variation in its drainage is even greater than that of the Nazas. Sometimes its bed is dry for two, three, or even four years causing ruin to the fields in the region it affects. Very few studies have been made of the Aguanaval but it can be said that in years of abundant water as much as 20,000 acres may be irrigated.

The run-off from the Nazas varies in volume, in time of arrival, and in continuance of flow, having dry, medium, and abundant years. The river bed is usually dry, the flood waters beginning during the last days of June or later and lasting until October, the greatest volume usually being in August or September. Occasionally the water flows until November or later, but when this happens, the volume is small.

When the capacity of all the canals is insufficient to fully distribute the run-off, the surplus water flows into the Laguna de Mayran located twelve miles below San Pedro. This water is lost as the excess waters have never been used to any advantage nor are there any means of using them at the present time. There is enough land, much more than enough to utilize the largest amount of water yet recorded for any one year. In spite of this, the water loss is 12 per cent of the total volume drained.

The just and fair distribution among the different sectors of the Region which have the right to this water constitutes a problem of vital importance. The main irrigation net is

formed by 29 primary canals which part directly from the Nazas. These canals have ten draining dams with their corresponding permanent works. The topographical order in which the dams and canals are located may be determined by consulting the drainage map. The capacity of these canals is approximately 35,314.5 cubic feet per second.

The actual irrigated area of Laguna will be increased by two important projects. 1) To prevent infiltration losses, canal linings will be installed in the smaller ditches and later in the larger distributaries. Conveyance losses in the main canals and sublaterals are not as great as in the smaller distributaries, 20 per cent being the loss in the small ones and 10 per cent the loss in the others. This work will require many years. 2) The flood discharge of the Nazas will be regulated by the construction of a regulating reservoir, the Palmito Dam. The Mexican government is building Palmito Dam with a total capacity of 2,430,000 acre-feet. The completion of which will cost 52,000,000 pesos. The dam is located on the Nazas above Torreón and may

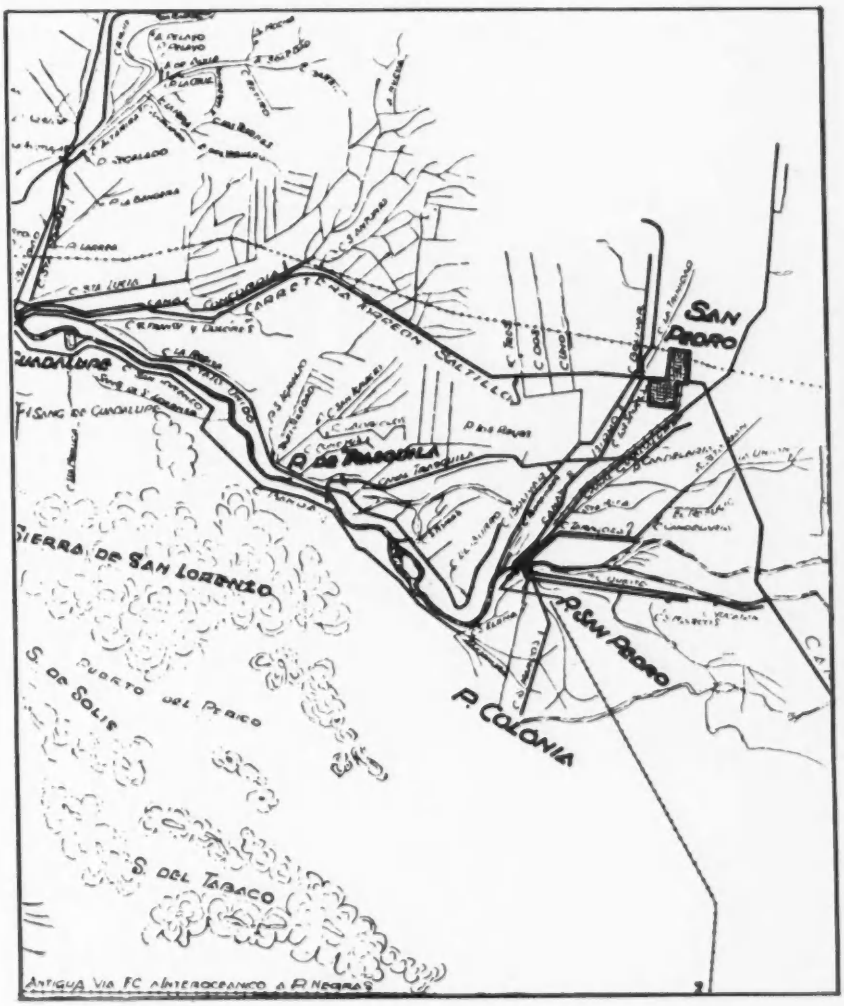

FIGURE 1.—Location of Laguna Area.

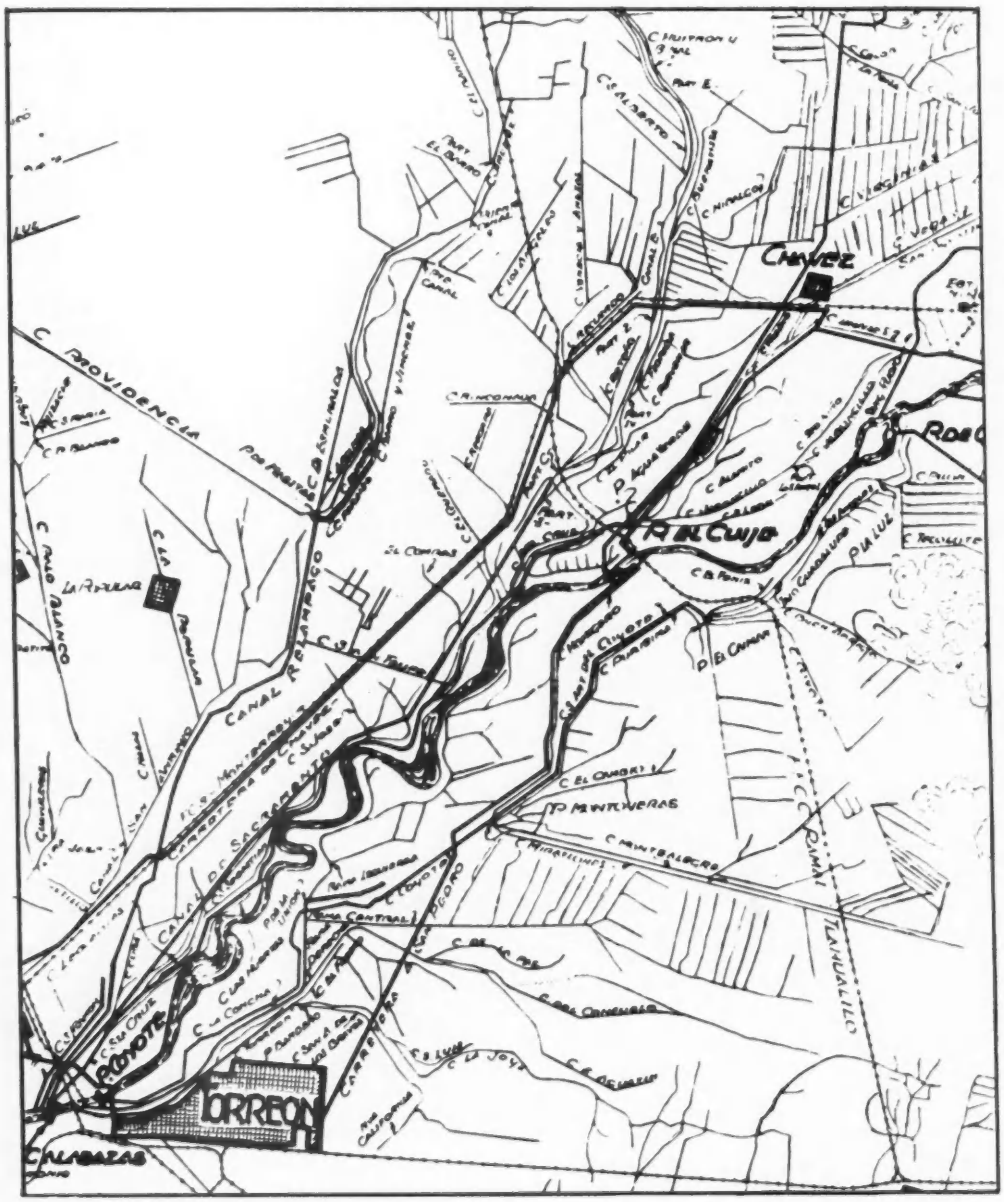

FIGURE 2.—Drainage map showing the irrigation system with canals and dams.

be completed late in 1944. The dam will irrigate about 450,000 acres, at regular intervals, thereby eliminating poor crops caused by a shortage of water. It will also enable the Region to use the water at a time when its application is most needed. Even those who dispute the claims of an increase of land admit that there will be no cycles of good and bad years dependent upon the irregular flow of the Nazas. Thus, the whole economy of the Region may be improved.

In the Laguna Region, 1,500 wells are used to supplement the river water. The area that these wells can irrigate

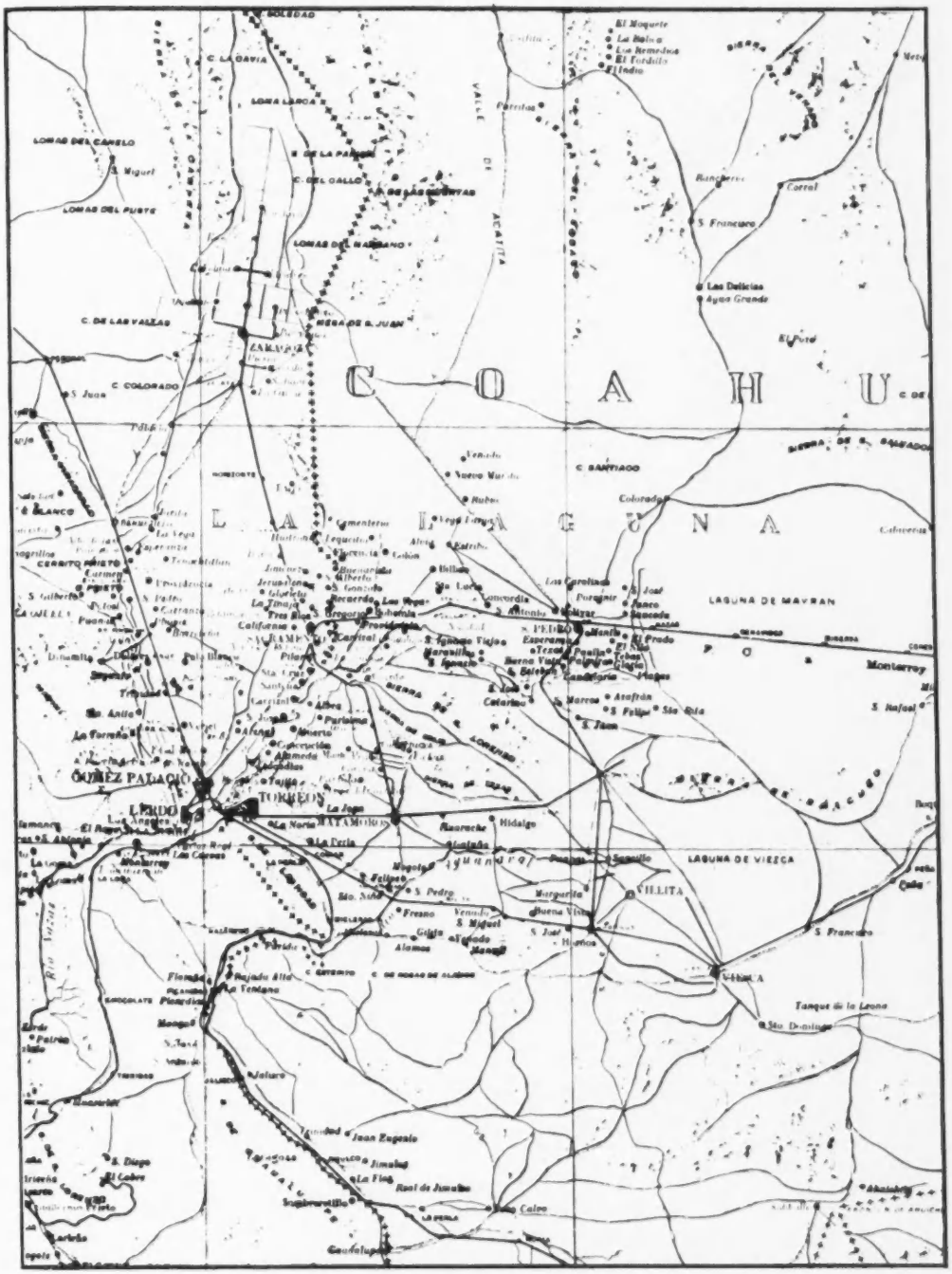

FIGURE 3.—Drainage map showing the irrigation system with canals and dams.

is estimated at 180,000 acres. Very few more can be drilled since the water level is now as low as safety will permit. At the present time, wells are being drilled with the needs of the Region as a whole taken into account, instead of in the "wildcat" manner which threatened the underground water level of

the district. Around Viezca, there is an additional source of water. Hot springs in the mountains permit four irrigations some forty days apart to a limited area.

Cotton and wheat have been mainly adopted in the Laguna Region, due to climatic conditions and to the method of irrigation. These two crops comprise 96 per cent of the total cultivated area. Cotton attains great production in relation to the area cultivated and ranks high among the countries cultivating cotton. With wheat, the production per unit is among the highest in the country. Putting the loans and profits together, it is clear that in the cultivation of cotton with animals, light machinery and heavy machinery, the rates of income per farmer were larger than in the cultivation of wheat under the same conditions with the same machinery. At present, it is necessary to grow wheat in areas infested with Johnson grass. Wheat is also popular in the districts which lack deep wells and a soil which will retain sufficient moisture from the time of the floods until the end of the vegetative cycle of the cotton plant. This cycle is from three to four months longer than that for wheat. The actual conditions of the irrigation system do not permit the introduction on a large scale of new crops which could be substituted for cotton and wheat.

Alfalfa and corn follow cotton and wheat in importance. The cultivation of alfalfa entered this Region slowly. It came because of the necessity to furnish forage for the milch cows, to feed the work animals and also as a means of insuring the farmers against fluctuations in the price of cotton and the dependence on one crop. Moreover, because of the ground and the climate a large yield is obtained from alfalfa growing. It has been suggested that sorghum would fit into the Region more advantageously than alfalfa since alfalfa needs more regular irrigation than is generally possible throughout the year. The cultivation of maize was gradually abandoned and at the present time is only cultivated in small amounts. The former landowners asserted that it was cheaper to buy it than to sow it.

FIGURE 4.—One of the larger irrigation canals.

FIGURE 5.—A fallow field.

Many ejidos also raise watermelon and cantaloupes. One ejido has planted 25,000 grape vines as an experiment in ejidal grape cultivation. Fruit trees are cultivated on a small scale, reaching an important status in only two towns of the Region. Fruit trees, grapes, and vegetables should give splendid results in this Region since there is clear weather for over 300 days of the year.

One of the most striking changes since 1936 is in the variety of crops

FIGURE 6.—Exterior view of a cotton gin.

grown. Before expropriation, since all the water had to be paid for by landlords, the only profitable crops were cotton, wheat, corn, and alfalfa. Fruits and vegetables were imported at high prices and most of the peasants never tasted them, their diet being corn, beans, and meat. Because the inhabitants in the surrounding region, depend upon mining for their income, wheat, alfalfa, corn, and fruit should be very profitable in Laguna. The tariff protection is now extended to wheat and flour as a stimulus to wheat production. As a result, several of the Laguna plantations are now depending on wheat for an increasing proportion of their cash crops. It is possible considering the handicaps of cotton production and the relative price of the two crops, that the wheat acreage will increase at the expense of the cotton.

As raisers of livestock, the states of Coahuila and Durango are not as important as other states due to the lack of streams. The kinds of stock which promise the best results are sheep and goats, but hogs and milch cows might bring very good results in the Laguna Region, the cattle feeding on alfalfa pastures. To date very little has been done to develop the livestock industry, for in this Region there is almost no pasture where even the work animals can be maintained economically during the dull months. The Ejidal Bank financed one ejido in the purchase of Jersey and Holstein cows as an experiment in teaching peasants to raise dairy cattle.

The Ejidal Bank advised the peasants of Laguna to end regional dependence on cotton, a crop subject to violent fluctuations on the international market. Table I shows the cycles in the production of cotton and wheat. Analyzing those figures, it can be noted that the cotton area has steadily decreased from 1935–36 to date. This was due in part to the fact that the land could not be farmed with cotton by reason of the Johnson grass or because the irrigation water was not retained from the floods for the vegetative cycle of the cotton plant. The main reason, however, was due to the new governmental policy of crop diversi-

FIGURE 7.—Interior view of a cotton gin belonging to the Ejidal Bank.

fication. Wheat sowing was increased roughly from 76,000 acres in 1936–37 to 128,000 acres in 1937–38 and to 178,000 acres in 1938–39. In 1940–41, it dropped to 140,995 acres.

No other plant is as suitable as cotton in the Laguna Region considering the amount of moisture available at the present time. The character of the growing season, frost-free from March to November, is also a factor favoring cotton. On each ejido in Laguna, one-half of the fields are flooded three feet deep between August and November. By December, the water has soaked in, and by February, the soil is dry enough for plowing and harrowing. The cotton crop is planted from February to May and occasionally as late as June. The middle of March is usually the latest time for sowing to avoid the ravages of the pink bollworm.

The sowing is done by hand, or by machine, by dropping the seed thickly into furrows a meter apart. A month later when the plants are six inches high, they are thinned out to one foot apart and the land between the furrows is cleaned and cultivated. Most of the crop is grown with no water other than that which was allowed to soak into the land the previous autumn. If water flows down the river in July, the yield will increase 50 per cent because the plants will suffer less from drought and will increase their number of bolls although this watering aids the pink bollworm. Picking begins in July and often continues to as late as November. Every planter endeavors to harvest the crop as quickly as possible to avoid the pink bollworm. Pickers are paid by weight and the peons pick 70 kilos per day during a seven-hour day.

The cost of production in Laguna is high due to the heavy expense of building ditches and borders, high prices for implements and tools and to the inefficiency of labor. In ejidal production, the ploughing, hoeing, weeding, etc. with machines is efficient only where the ejidatario possesses a parcel of land exceeding his own labor capacity. A high percentage of parcels over ten acres, whether because of the poor quality of their soil or because of insufficient rainfall, do not justify the expenditure involved in the purchase of machinery but parcels over twenty-five acres should be economically worked with mechanized equipment. Practically all of the machinery used in Laguna is manufactured in the United States showing that this project has benefited American industrial production. The following machinery was used in the Laguna Region during 1941: 171 threshing machines, 2 214 ploughs, 1,357 disc harrows, 4,337 sowing machines, 115 packers, 780 clod crushers, 12,586 cultivating machines, 2,148 scrapers, 136 trucks, and 373 wagons.

In 1941, 21,731 mules were used in the Region. These animals should be used exclusively in the cultivation of

TABLE 1

AREA CULTIVATED IN COTTON AND WHEAT IN LAGUNA*

Years	*Total Area Cultivated in Cotton and Wheat*	*Cotton*	*Wheat*
	Hectares	*Hectares*	*Hectares*
1925–26	137,174	119,733	17,441
1926–27	100,528	52,492	48,036
1927–28	115,670	94,480	21,190
1928–29	109,918	76,950	32,268
1929–30	91,385	78,844	12,541
1930–31	123,486	68,870	54,616
1931–32	84,722	43,731	40,991
1932–33	139,305	78,830	60,475
1933–34	96,171	60,751	35,420
1934–35	90,384	66,468	23,916
1935–36	171,961	133,100	38,861
1936–37	142,397	111,944	30,453
1937–38	128,969	77,472	51,497
1938–39	144,853	73,329	71,524
1939–40	136,860	73,320	63,540
1940–41	125,398	69,000	56,398

*Gomez, M. R., *La Region Lagunera*, Mexico, 1941.

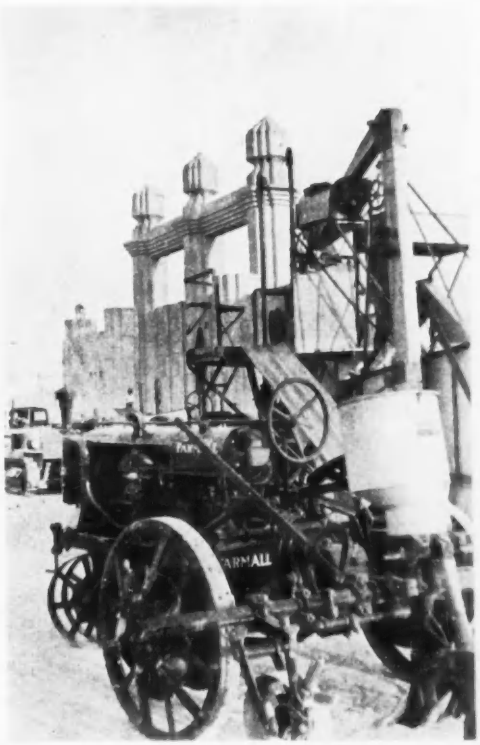

FIGURE 8.—An exhibit of Laguna Region machinery.

cotton and never in the preparation of the soil. In this way, a large saving is obtained since they only remain in the corrals of the farms the four months of the yearly cultivation periods and are in pasture for the remaining eight months. Feeding animals is very expensive here. In 1937, the cost per mule per day was more than the cost of feeding a family.

Under private ownership, there were 118 ginning plants in the Region but they were uneconomically placed for collective farming. Only 60 of them located at carefully chosen strategic spots could be employed by the ejidos. The latest machinery was provided for many of them and the peasants' own plants did 42 per cent of the ginnings of the entire Region in 1939. In its first two years, the Santa Teresa gin made a profit of 60,000 pesos, one-half of the cost of the plant. In the ginning process, the fiber is passed through a saw gin because of the short staple and the ginned cotton is carried to a press where it is compressed into bales weighing 478 pounds. The bale covering is open mesh fabric made from ixtle Mexican cotton is neither ginned nor baled as well as American. General storage depositories press, store, distribute, and export both cotton and seed. The Ejidal Bank owns fourteen warehouses for the storage of crops until they can be shipped or until markets are favorable. The principal markets of the Region are the states of Pueblo Vera Cruz, and the Federal District. Other regions are also supplied and some cotton is exported.

There are certain disadvantages in growing cotton in Laguna. Plagues are numerous. One may be quelled but

FIGURE 9.—Cotton growing in Gomez Palacio municipality.

then another seems to take its place as was done by the Johnson grass in the last few years. There are many years when the water supply is insufficient, but again, this should be corrected with the completion of Palmito. All of the machinery for the mills and the food and supplies have to be imported which raises the cost of production. The climate is not adapted to the manufacture of cotton so that most of the cotton has to be shipped to other sections of the country. For many years, climate will no doubt play an important part in the manufacture of cotton in Mexico although it has ceased to be a hindrance in the United States. Labor is high in the Region in proportion to its efficiency.

In spite of these disadvantages, the outlook for increased cotton production in Laguna depends largely upon national as well as upon natural conditions. Should the cotton consumption of the Mexican mills increase considerably or should world production prices improve, it is probable that cotton production would expand in the Region. In the past, in years of high prices for cotton, cotton acreage has been increased at the expense of the food crops. However, the cotton acreage is very definitely limited to the amount of water available.

Wheat is the desirable supplementary crop. It is planted after the cotton harvest in early winter and matures before the flooding in the following summer thus using labor at slack periods and occupying fields that otherwise would be left idle. Unfortunately, wheat requires irrigation in January when only a small and uncertain amount of water

FIGURE 10.—The Nazas at Coyote dam.

is available. However, this irrigation problem will be removed with the completion of the Palmito Dam. Cotton is not free from competition of other crops in the Region. It is possible that wheat may become the important crop. It appears to be governmental policy to encourage the smaller farmers to grow their own food requirements. This practice, if it becomes widespread, may have a tendency to retard or even prevent the large and rapid expansion of the cotton acreage.

The Laguna Region is the most productive cotton region in Mexico. Under an improved irrigation system, such as is promised by the Palmito Dam, there should be economic security and the agricultural production of the Region should become less of a gamble than it has been to date. Surplus volumes of water in years of plenty will fill the deficiencies of the years of drought, regularizing, in this way, the areas which are irrigated each year. The Region should expand under the present two crop agricultural system, becoming one of the most important agricultural sections, not only in the northeastern plateau but in the whole of Mexico.

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"Nature has been so silent in her persistent influence over man, that the geographic factor in the equation of human development has been overlooked."

ELLEN CHURCHILL SEMPLE

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